



Universidade do Minho
Escola de Engenharia

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Student anthropometrics data and its
application in school furniture design

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application in school furniture design

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and Systems Engineering

Trabalho efectuado sob a orientação do
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STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of the thesis elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

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Abstract

School can be considered the first workplace in our life. In this workplace situation, school furniture is a key factor for the adoption of a proper body posture. Many factors can generally influence the students' sitting posture, such as the anthropometric dimensions of schoolchildren, as well as the measurement and design features of the school furniture. School furniture is not the only cause of pain and discomfort reported by school children. However, being seated for a long period of time in school furniture is being associated to reports of musculoskeletal discomfort and pain. School furniture dimensions, within the context in which it is used, may also have an impact on some physical and performance aspects of the students. The aim of this thesis was to study the students' anthropometrics data and its application for school furniture design. The methodology can be divided in two processes. The first one was the field work, where eight anthropometric measures were gathered from 3,181 students, together with six furniture dimensions. The second process include two literature reviews, which was used to identify the studies previously carried out in the field of the anthropometric (mis)match and the relationship between school furniture and the effects on students' performance and physical aspects. The obtained results show that the compatibility between school furniture dimension and student anthropometric characteristics was identified as a key factor, mainly to improve some students' physical aspects. The design characteristics of the furniture, such as high furniture comparing the dimensions of the users, sit-stand, tilt table and seat, present positive effects. Regarding the definition of the (mis)match equations, six furniture dimensions were evaluated with a high number of applied equations. Seat height was also the most evaluated furniture dimension and there were considerable differences between the two most frequently used equations. It was also verified that the Chilean student population presents a positive secular trend in different anthropometric dimensions, such as stature, popliteal height, hip width and buttock popliteal length. Many different types of school furniture, or school sets, are used at the analysed schools. These furniture sets presented a high level of mismatch for seat height, desk height and seat-to-desk clearance. The application of the Chilean standard resulted in highest level of mismatch in desk height and seat depth. The level of fit improved in the six evaluated dimensions with the data obtained in this thesis and proposed to be used as an updated standard. Finally, the use of the popliteal height for selecting the furniture set presented a lower level of mismatch when compared with stature. Considering the obtained results in this thesis, it can be concluded that the dimensions of the school furniture is relevant and may have an effect on the some students physical aspects. The proposed methodology for the evaluation of school furniture suitability should allow for a more reliable and accurate analysis of school furniture. Additionally, it should be highlighted that it is of paramount importance to monitor the students anthropometrics characteristics with the final aim of updating the furniture standards and that the selection of furniture should be made by using the popliteal height, instead of the typical selection that uses the students' stature.

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Resumo

A escola pode ser considerado o primeiro local de trabalho na nossa vida. Neste “local de trabalho”, o mobiliário usado é um fator-chave para a adoção de uma postura corporal adequada. São inúmeros os fatores que podem influenciar a postura dos alunos na posição de sentados, tais como as suas dimensões antropométricas, bem como as dimensões e o desenho do mobiliário escolar. O mobiliário escolar não é a única causa para o aparecimento de dor e desconforto músculoesquelético em crianças em idade escolar. No entanto, o facto de ter de estar sentado por um longo período de tempo vem sendo associado a relatos de desconforto e dor músculoesquelética. As dimensões do mobiliário escolar, no contexto em que é usado, podem também ter um impacto sobre alguns aspectos físicos dos alunos e no seu desempenho. O objetivo desta tese consistiu em estudar os dados antropométricos de uma amostra de alunos e a sua aplicação no desenho e concepção do mobiliário escolar. A metodologia aplicada pode ser dividida em duas partes. A primeira consistiu no trabalho de campo, onde oito medidas antropométricas foram recolhidas a partir de uma amostra de 3.181 alunos, juntamente com seis dimensões do mobiliário. A segunda parte inclui duas revisões de literatura, que foram desenvolvidas para identificar os estudos anteriormente publicados sobre o tema da (in)compatibilidade antropométrica e a relação entre o mobiliário escolar e os efeitos deste no desempenho dos alunos e em alguns aspectos físicos destes. Os resultados obtidos mostram que a (in)compatibilidade entre as dimensões do mobiliário escolar e das características antropométricas dos alunos é identificado como um fator-chave, principalmente para melhorar algumas questões de natureza física. As características de desenho do mobiliário escolar, como por exemplo mobiliário de maiores dimensões que os seus utilizadores, a posição sentado-de pé, a inclinação do tampo da mesa e do assento, também mostraram poderem ter efeitos significativos. No que diz respeito à definição das equações de (in)compatibilidade (ou *mismatch*), seis dimensões do mobiliário foram avaliados através de um elevado número de equações. A altura do assento foi a dimensão do mobiliário mais avaliada, tendo-se verificado diferenças consideráveis entre as duas equações que são habitualmente utilizadas. Verificou-se também que a população estudantil Chilena analisada apresenta um crescimento secular positivo, o que é verificado em várias dimensões antropométricas, tais como a estatura, a altura do poplíteo, a largura das ancas e comprimento coxa-poplíteo. As escolas analisadas possuíam vários tipos diferentes de mobiliário escolar, ou conjuntos de mobiliário. Estes conjuntos de mobiliário apresentaram elevados valores de incompatibilidade ao nível da altura do assento, altura da mesa e no espaço entre o assento e a mesa. A aplicação da norma Chilena para a seleção do mobiliário adequado resulta num valor mais elevado de incompatibilidade no que diz respeito à altura da mesa e à profundidade do assento. O nível de incompatibilidade diminui em seis dimensões avaliadas caso sejam considerados os dados obtidos no decorrer desta tese e que são propostos para atualizar a norma Chilena referida anteriormente. Finalmente, a utilização da altura do poplíteo para selecionar o conjunto de mobiliário resulta num menor nível de incompatibilidade, quando comparada com a seleção feita a partir da estatura dos alunos. Considerando os resultados obtidos, pode concluir-se que as dimensões do mobiliário escolar são importantes e podem ter um efeito relevante sobre alguns aspectos físicos dos alunos. A metodologia proposta para a avaliação da adequação do mobiliário escolar ao aluno permitirá que esta análise seja mais fiável e precisa. Além disso, deve-se ressaltar que é de extrema importância avaliar continuamente as dimensões antropométricas dos alunos com o objectivo final de atualização das normas relativas à seleção do mobiliário, que por sua vez deverá ser feita usando a altura do poplíteo, em vez da estatura.

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List of Abbreviations and Acronyms

BPL	Bottom Popliteal Length
ChS	Chilean Standard 2566
DD	Desk Depth
DH	Desk Height
DW	Desk Width
EHS	Elbow Height Sitting
HBR	Height of Backrest
HW	Hip Width
ICH	Iliac Crest Height
KH	Knee Height
LEBR	Lower Edge of Backrest
LH	Lumbar Height
PH	Popliteal Height
S	Stature
SbS	Selection by Stature
SbPH	Selection by Popliteal Height
SD	Seat Depth
SDC	Seat to Desk Clearance
SDH	Seat to Desk Height
SH	Seat Height
SHS	Shoulder Height Sitting
SUH	Subscapular Height
SW	Seat Width
TT	Thigh thickness (TT)
UDH	Underneath Desk Height

UEB Upper Edge of Backrest

UpS Updated Standard

WBR Width of Backrest

CHAPTER 1 | Introduction and Thesis Overview

1.1. Motivation

Students are exposed to the first systematic tasks or activities that human beings carry out in their life while at school, due to this it can be assumed that school became the first workplace in our life. Within a school, the 'system' contains many different 'elements', these can include school equipment (e.g. desks, chairs, computers, laptops, books, schoolbags, pens), work (e.g. learning, teaching and playing) - workspaces (e.g. desk/chair/workspace arrangements, lockers), school environments (e.g. physical factors, such as heating, cooling, lighting, noise, building design and the internet) and school organization (e.g. subjects/topics, curricula, learning/teaching methods and pedagogy, school-day length, rest breaks, physical activities, departmental structures) Legg (2007).

The approach of the ergonomists starts by considering the person doing the work as a central element and aims to create a work system that allows the worker/students to do what is required in a safe, efficient and satisfactory way (Corlett 2009). In the educational arena, the benefits that the application of Ergonomics science to the design of educational systems features and operations might bring to promote students learning have yet to be widely recognized (Smith 2013). Following the ergonomists approach and the principles defined by Smith (2007) and Legg (2007), it can be stated that when considering the school as a workplace situation (Figure 1.1.), there are a group of dependent variables (physical aspects and students' performance) that may be influenced by some macro-ergonomics variables (environment and organization) and micro-ergonomics variables (school furniture, activities and school bags). Furthermore, it is important to notice that there is some interrelation between variables, such as:

- The activities must be considered for the definition of the design of school furniture;
- The features of the students and their activities must be considered to define the school furniture standard;
- The interaction between the students anthropometrics and the school furniture will determine the level of (mis)match.

Legg and Jacobs (2008) mention that very little research (and even less practical application) has been focused on macro-ergonomics issues. Organization is an important issue in macro-ergonomics, as an example the report of Smith (2013) shows that longer exposure to learning, cooperative learning designs and teaching quality have shown to have a strong influence in the students' performance. In the other hand, smaller class size (classroom size), school schedules (start time) and the amount of homework have a weak influence in the students' performance.

Another macro-ergonomics aspect is the school environment, which consists in a number of variables that can influence the students' performance and classrooms perception, such as temperature, indoor air quality, noise exposure and lighting. For example, students generally accepted cool thermal sensations more readily than warm thermal sensations (Wong and Khoo 2003). Furthermore, from the study of Lackney (2000) it can be stated that temperature influences students' performance in math and reading.

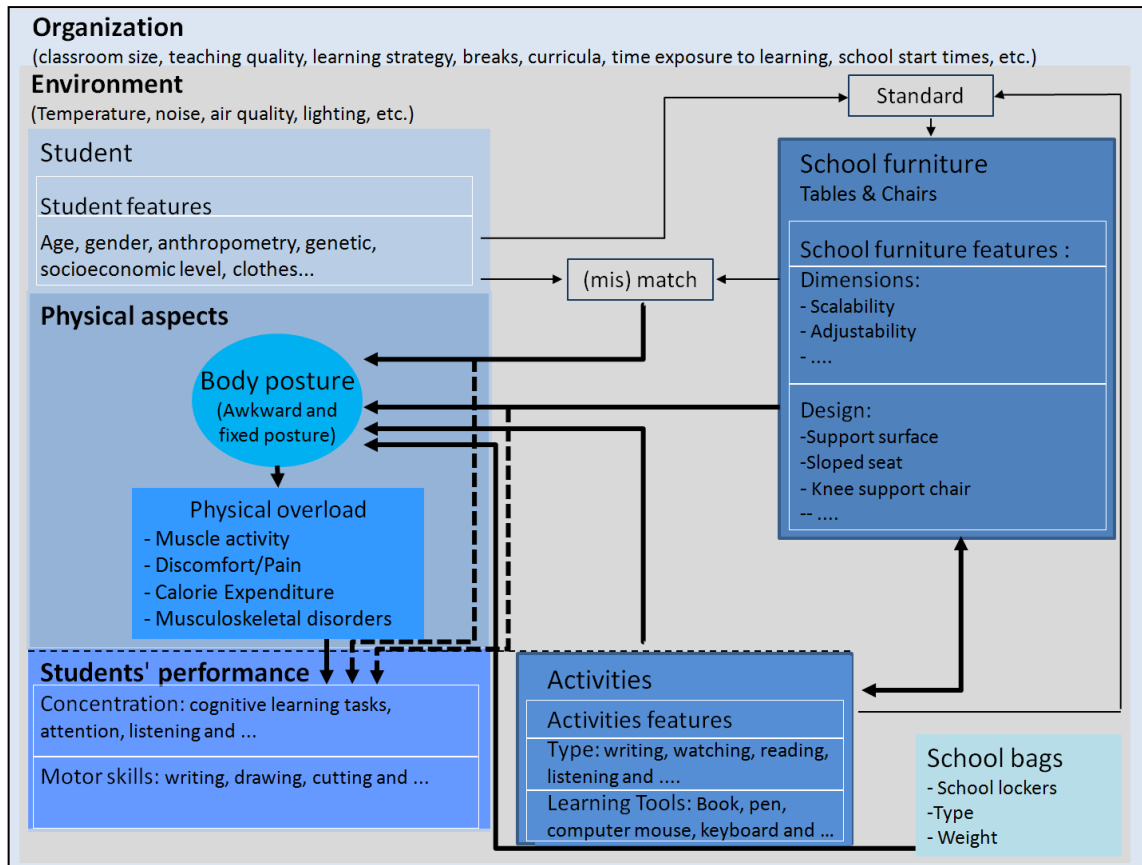


Figure 1.1. Diagram of school as a workplace situation

Indoor air quality is also an important variable, since low ventilation rates can have a negative impact on the absence rate and on the health of children (Shendell et al. 2004). Bakó-Biró et al. (2012) shows that low ventilation rates in classrooms significantly reduce pupils' attention and vigilance, and affect negatively their memory and concentration.

The school environment should promote an atmosphere that induces everyone's interest in listening and being involved in communication. Therefore, the social benefit of noise reduction is an environment with pleasant, or at least acceptable noise levels, preserving the health of its users as a whole and improving the students' scholastic performance (Zannin and Zwirter 2009).

Regarding the micro-ergonomics variables, the activities undertaken by the students in the class are influenced by different factors (learning tools, classroom size, teaching quality, etc). The learning tools available at the school have presented some changes during the last decades, basically since the explosive growth in the use of different computers, software packages, and computer-based technologies in the classroom (Straker and Pollock 2005). While classroom technology has generally been viewed as a positive addition, in some cases technology has been found to have no impact or even a negative impact on the students' learning experiences (Lowerison et al. 2006, Schmid et al. 2009)

In the present century, there has been a growing concern among teachers, parents, and health care professionals over the effect of school bags on musculoskeletal problems in children and adolescents (Amiri et al. 2012, Bauer and Freivalds 2009, Brackley et al. 2009, De Paula et al. 2012, Dianat et al. 2013, Dockrell et al. 2013, Lindstrom-hazel 2009, Mackie et al. 2003, Moore et al. 2007, Pau and Pau 2010, Skoffer 2007, Whittfield et al. 2001).

Children spend more than four hours per day sitting down while doing their school work (Oyewole, Haight, & Freivalds, 2010). Considering the amount of time spent at school and specifically while sitting, it is fundamental that school furniture suit the children's requirements (Savanur et al., 2007), and it should also allow for the changing of postures (Yeats, 1997).

It can be observed an increased concern about the school classrooms, in particular about the study and design of school furniture suitable to the needs of the students and with appropriate dimensions according to the students' anthropometrics characteristics. In Chile, an important milestone in this increasing concern is the publication of the Chilean standard No. 2566 (INN, 2002), which determines the dimensions and characteristics of different types of school furniture for the whole Chilean student population.

Despite that, in one study carried out with Chilean students, Castellucci, Arezes and Viviani (2010) concluded that classroom furniture was, in almost all the analysed cases and subjects, not fully adequate for the student population. Seat Height and Seat to Desk Height were the furniture dimensions with a higher level of mismatch.

After the completion of the mentioned study, during 2010, the Chilean decree 393 was published, which states that Chilean schools should have school furniture according to current standards by the National Institute of Standardization. The main aim of this decree was to generate safer schools and counteract the lack of knowledge and applicability of the Chilean standard N° 2566.

It is important to mention that in the lasts decades a positive secular growth in different countries have been observed, with an average growth between 0.7 and 4.0 cm per decade (Jung, 2005). This secular growth has increased due to changes in living standards and dietary habits (Harris & Straker, 2000). Although none of these studies considered the Chilean population, secular growth is a very important factor to consider, because the

anthropometric data used in the Chilean standard No. 2566 was obtained in 1990, which may indicate that the standard may be out of date. Moreover, the standard, like most of the standards worldwide used for furniture selection, tend to use, as reference, the stature of the school children, assuming that all the other anthropometric characteristics will be also appropriate or suitable. However, a few authors, including Molenbroek et al. (2003), suggest that the furniture selection can be carried out more efficiently by using the popliteal height instead of stature.

1.2. Objectives

The main objective of this thesis is the study of the students' anthropometrics data and its application in the design of school furniture.

In order to achieve the defined general goals, the following more specific objectives were also considered:

1. Determine the influence of school furniture in the students' performance and physical aspects.
2. Determine the criteria equations for defining the (mis)match between students and furniture.
3. Analyze the suitability of school furniture dimensions in the Valparaiso Region.
4. Make a revision of the Chilean Standard for the dimensions of school furniture.
5. Determine if Popliteal Height is a better measure for classroom furniture selection than Stature.
6. Propose a new standard for furniture dimensions in Chilean schools.

1.3. Thesis Synopsis

Most of the chapters of this thesis, namely those from 2 to 8 (Figure 1.2.), consist of a compilation of studies that were also developed as scientific papers, which seek to accomplish with the research objectives previously defined. Although almost all the papers were already published (or submitted in its final format), some of them had been changed in this thesis as some minor errors were identified later, namely some small typographical or grammatical errors. The "status" of each paper is indicated in the beginning of each chapter. Additionally, the thesis has also two more chapters, one in the beginning and one at the end, as described in the following paragraphs.

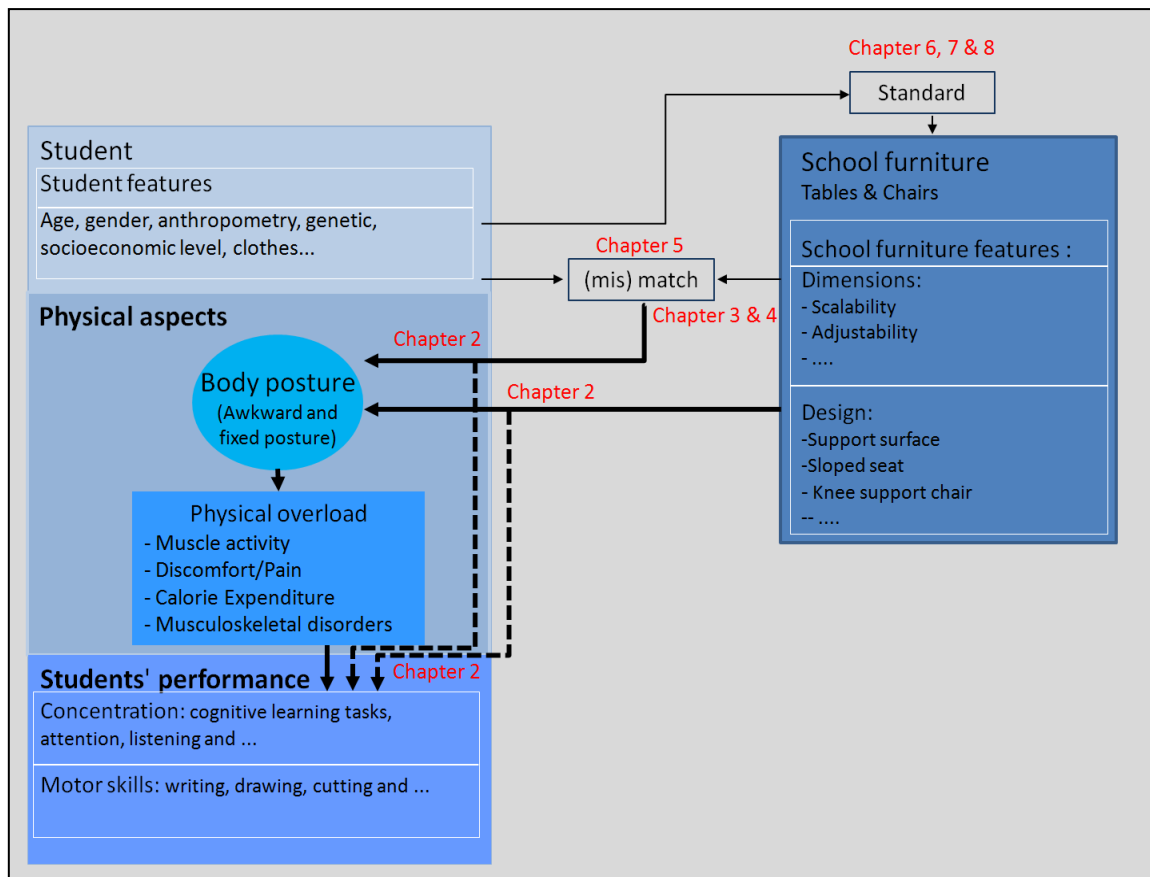


Figure 1.2. Diagram of the distribution of the Thesis chapters

Chapter 1 is an introduction to the subject and to the thesis and where it is presented the context and motivation of this work, as well as its objectives.

Chapter 2 and Chapter 3 are two systematic reviews focused on two important issues regarding school furniture. Chapter 2 gives an overall picture of the influence of school furniture on the students' performance and physical aspects. Considering the bibliography published, the study try to clarified how the design and/or dimension of school furniture affect the students' physical aspects and/or their performance. For its turn, chapter 3 corresponds to the second study performed, entitled "Equations for defining the mismatch between students and school furniture: a systematic review". This study analyzes the level of mismatch found in the literature under review by discussing the various criteria equations and by proposing a methodology to evaluate school furniture suitability.

Chapter 5 presents the fourth study "Evaluation of the match between anthropometric measures and school furniture dimensions in Chile". In this study, using the methodology developed in the previous chapter, the objective was to determine the potential mismatch between school furniture dimensions and anthropometric characteristics of the students from the Valparaíso region of Chile.

Chapter 6 corresponds to the fifth study performed and presented two main objective: i) To analyse if the Chilean student population has registered a secular growth between 1990 and 2012; and ii) To verify if Chilean Standard 2566 data is still valid to fit, or match, the current student anthropometric characteristics. This chapter has also the ambition to analyse how the secular growth influences the level of mismatch.

The sixth study is presented in chapter 7, which was entitled "Analysis of the most relevant anthropometric dimensions for school furniture selection based on a study with students from one Chilean region". Using the entire sample, this study analysed how the use of two different anthropometric dimensions (Popliteal Height and Stature), used for allocation or selection of the school furniture, will impact in the level mismatch.

The last performed study, chapter 8, was entitled "An update to the Chilean standard for school furniture dimension specifications", and it explains the procedure to update the data of the standard and shows the dimensions of the school furniture that can be used in the updated standard. Furthermore, it analyses the differences in the levels of mismatch between the current Chilean Standard and the proposed data to the Updated Standard.

Finally, chapter 9 summarizes the carried out work and the main conclusions obtained at the different studies and suggests possible directions for future work in this specific domain.

References

- Amiri, M., Dezfooli, M. S., & Mortezaei, S. R. (2012). Designing an ergonomics backpack for student aged 7-9 with user centred design approach. *Work (Reading, Mass.)*, 41 Suppl 1, 1193–201.
- Bakó-Biró, Z., Clements-Croome, D. J., Kochhar, N., Awbi, H. B., & Williams, M. J. (2012). Ventilation rates in schools and pupils' performance. *Building and Environment*, 48, 215–223.
- Bauer, D. H., & Freivalds, A. (2009). Backpack load limit recommendation for middle school students based on physiological and psychophysical measurements. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 32, 339–350.
- Bennett, C. (2002). Computers in the elementary school classroom. *Work: A Journal of Prevention, Assessment & Rehabilitation*, 18, 281–285.
- Brackley, H. M., Stevenson, J. M., & Selinger, J. C. (2009). Effect of backpack load placement on posture and spinal curvature in prepubescent children. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 32, 351–360.
- Castellucci, H. I., Arezes, P. M., & Viviani, C. A. (2010). Mismatch between classroom furniture and anthropometric measures in Chilean schools. *Applied Ergonomics*, 41(4), 563–568.
- Corlett, E. N. (2009). Ergonomics and sitting at work. *Work (Reading, Mass.)*, 34(2), 235–8.

- De Paula, a J. F., Silva, J. C. P., Paschoarelli, L. C., & Fujii, J. B. (2012). Backpacks and school children's obesity: challenges for public health and ergonomics. *Work (Reading, Mass.)*, 41 Suppl 1, 900–6.
- Dianat, I., JavadiVala, Z., Asghari-Jafarabadi, M., Asl Hashemi, A., & Haslegrave, C. M. (2013). The use of schoolbags and musculoskeletal symptoms among primary school children: are the recommended weight limits adequate? *Ergonomics*, 56(1), 79–89.
- Dockrell, S., Simms, C., & Blake, C. (2013). Schoolbag weight limit: can it be defined? *The Journal of School Health*, 83(5), 368–77.
- Harris, C., & Straker, L. (2000). Survey of physical ergonomics issues associated with school childrens' use of laptop computers. *International Journal of Industrial Ergonomics*, 26(3), 337-346.
- INN (Instituto Nacional de Normalización Chile). (2002). *Norma Chilena 2566. Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales*. INN, Santiago de Chile.
- Jung, H. S. (2005). A prototype of an adjustable table and an adjustable chair for schools. *International Journal of Industrial Ergonomics*, 35, 955-969.
- Lackney, J. A. (2000). Thirty-three educational design principles for schools & community learning centers. *ERIC Clearinghouse*.
- Legg, S. (2007). Ergonomics in schools. *Ergonomics*, 50(10), 1523–9.
- Legg, S., & Jacobs, K. (2008). Ergonomics for schools. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 31, 489–493.
- Lindstrom-hazel, D. (2009). The backpack problem is evident but the solution is less obvious. *Work: A Journal of Prevention, Assessment & Rehabilitation*, 32, 329–338.
- Lowerison, G., Sclater, J., Schmid, R., & Abrami, P. C. (2006). Student perceived effectiveness of computer technology use in post-secondary classrooms. *Computers & Education*, 47(4), 465–89.
- Mackie, H. W., Legg, S. J., Beadle, J., & Hedderley, D. (2003). Comparison of four different backpacks intended for school use. *Applied Ergonomics*, 34(3), 257–64.
- Molenbroek, J. F. M., Y. M. T. Kroon-Ramaekers, and C. J. Snijders. 2003. "Revision of the design of a standard for the dimensions of school furniture." *Ergonomics* 46 (7): 681-694.
- Moore, M. J., White, G. L., & Moore, D. L. (2007). Association of relative backpack weight with reported pain, pain sites, medical utilization, and lost school time in children and adolescents. *The Journal of School Health*, 77(5), 232–9.
- Mydlarz, C. A., Conetta, R., Connolly, D., Cox, T. J., Dockrell, J. E., & Shield, B. M. (2013). Comparison of environmental and acoustic factors in occupied school classrooms for 11 e 16 year old students. *Building and Environment*, 60, 265–271.

- Oyewole, S. A., Haight, J. M., & Freivalds, A. (2010). The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *International Journal of Industrial Ergonomics*, 40(4), 437–447.
- Pau, M., & Pau, M. (2010). Postural sway modifications induced by backpack carriage in primary school children: a case study in Italy. *Ergonomics*, 53(7), 872–81.
- Savanur, C. S., Altekar, C. R., & De, a. (2007). Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics*, 50(10), 1612–1625.
- Schmid, R. F., Bernard, R. M., Borokhovski, E., Tamim, R., Abrami, P. C., Wade, C. A., & Al., E. (2009). Technology's effect on achievement in higher education: a stage I meta-analysis of classroom applications. *J Comput Higher Educ*, 21(2), 95–109.
- Shendell, D. G., Prill, R., Fisk, W. J., Apte, M. G., Blake, D., & Faulkner, D. (2004). Associations between classroom CO2 concentrations and student attendance in Washington and Idaho. *Indoor Air*, 14(5), 333–341.
- Skoffer, B. (2007). Low back pain in 15- to 16-year-old children in relation to school furniture and carrying of the school bag. *Spine*, 32(24), E713–7.
- Smith, T. J. (2007). The ergonomics of learning: educational design and learning performance. *Ergonomics*, 50(10), 1530–46.
- Smith, T. J. (2013). Designing learning environments to promote student learning: ergonomics in all but name. *Work (Reading, Mass.)*, 44 Suppl 1, S39–60.
- Straker, L., & Pollock, C. (2005). Optimizing the interaction of children with information and communication technologies. *Ergonomics*, 48, 506–521.
- Whittfield, J. K., Legg, S. J., & Hedderley, D. I. (2001). The weight and use of schoolbags in New Zealand secondary schools. *Ergonomics*, 44(9), 819–24.
- Wong, N. H., & Khoo, S. S. (2003). Thermal comfort in classrooms in the tropics, 35(February 2002), 337–351.
- Yeats, B. (1997). Factors that may influence the postural health of schoolchildren (K-12). *Work: A Journal of Prevention, Assessment & Rehabilitation*, 9(1), 45–55.
- Zannin, P. H. T., & Zwirtes, D. P. Z. (2009). Evaluation of the acoustic performance of classrooms in public schools. *Applied Acoustics*, 70(4), 626–635.

CHAPTER 2| The influence of school furniture on the students' performance and physical aspects: results of a systematic review

Paper submitted in November 2014 for publication as:

Castellucci, HI, Arezes, PM, Molenbroek, JFM, de Bruin, R, Viviani, C. (n.d.). The influence of school furniture on the students' performance and physical aspects: results of a systematic review. *Ergonomics*.

The aim of this study was to determine, through a systematic review, the main findings available in the literature regarding the relationship between school furniture and the effects on students' performance and physical aspects. The overall results shows that 64% of the review studies present positive results, i.e. proved effects; meanwhile, 24% present negative or no change/effect, with the remaining 12% of the studies showing an effect that was not clear. The compatibility between school furniture dimension and student anthropometric characteristics was identified as a key factor, mainly to improve some students' physical aspects. The design characteristics, such as high furniture, sit-stand, tilt table and seat, also present positive effects. Finally, it was possible to conclude that further research should be performed by deeply exploring some aspects regarding those variables, particularly by applying more objective measures complemented with controlled and prospective design.

Keywords: classroom; workstation; design; dimension

2.1. Introduction

Life as a student can be considered among the most sedentary occupations (Zacharkow 1987), where permanent habits of sitting are formed (Lueder and Berg Rice 2008). Furthermore, poor sitting habits acquired during childhood are very difficult to change later in adolescence and/or adulthood (Yeats 1997). Students are exposed to the first systematic tasks or activities that human beings carry out in their life while at school and as a result, it can be assumed that school became the first 'workplace' in our life. Legg and Jacobs (2008), mentioned that 'system' within schools contains many different 'elements', ranging from macro in nature (environment and organization) to micro in nature (school furniture, activities and school bags). De Bruin and Molenbroek (2010) proposed a diagram in which they include some of the relevant aspects of the school characteristics. This diagram seems to justify the consideration of schools as a 'workplace' (Figure 2.1.).

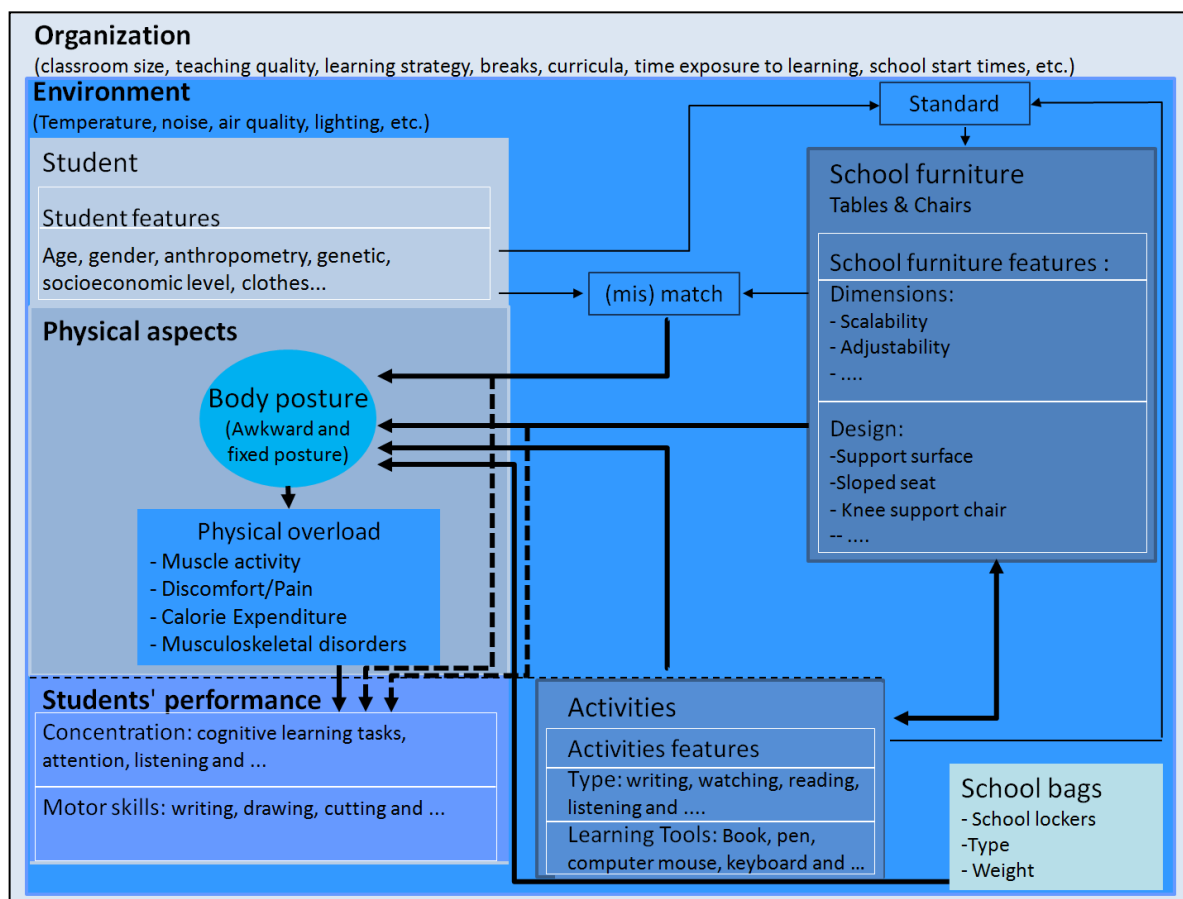


Figure 2.1. Diagram of school as a workplace situation (adapted from de Bruin and Molenbroek 2010)

In schools there seems to exist a conflict between the natural impulse of physical movement by children and the need to maintain a prolonged sedentary position for education purposes.

In normal school environments, many factors can generally influence the students' sitting posture. These include the anthropometric dimensions of schoolchildren, as well as the measurement and design features of the school furniture (Murphy, Buckle, and Stubbs 2007). There are a group of variables that need to be considered in the interaction between the school furniture and the students' characteristics (Figure 2.1.):

- School furniture design: In the last decades, the upright posture enforced on students had them sitting with the joints of their hips, knees and ankles at right angles. However, a 'normal' child can keep this posture for no longer than 1-2 minutes (Mandal 1981). Additionally, this posture can cause some biomechanical problems since a seated person has a hip joint flexion of about 60° and the pelvis has a sloping axis; therefore, the lumbar curve changes from a lordosis (standing position) to an kyphosis (sitting position) (Mandal 1994). This is also supported by the work of (Schoberth cited by Mandal 1981), who found from X-ray examinations of 25 people sitting upright, an average 60° hip flexion and 30° lumbar flexion. Many researchers have tried to improve the sitting position by modifying some aspects of the school furniture. In Zacharkow's (1987) book, there are some

references that show the relevance of the desk slope, such as those from Bennett (1922) ("In requiring a child to sit erect at an ordinary desk while reading or writing, we are demanding a physical impossibility") and from Dresslar's (1917) ("I believe the chief defect in desks now on the market is that the desk top is too flat").

The seat pan also represents an important element of the school furniture, since it carries about 80% of the trunk weight (Mandal 1994). Seat height is a very important issue that will be mentioned in the next section. Regarding the seat angle, the positive angle (or the forward sloping seat) is based on the principles that most work activities require a forward leaning posture, without any use of the backrest (Mandal cited by Lueder and Berg Rice 2008). Some authors argued that this design would reduce forward bending of the low back (lumbar flexion). Furthermore, the backrest or lumbar support will only have a beneficial effect if the chair presents a negative seat or a backwards sloping seat (Mandal 1994). However, in practice, the backrest may facilitate the forward movement of the buttocks and kyphosis of the lumbar spine to stabilize the trunk against the backrest (Bendix et al. 1996).

- School furniture dimensions: Students are often exposed to fixed-dimension furniture throughout their adolescent school life, with little opportunity for adjustability to suit their own changing anthropometry. This concern is made clear by the large number of studies published worldwide where a clear mismatch between anthropometric characteristics and the dimensions of the furniture under study has been identified (Agha 2010; Batista et al. 2012; Brewer et al. 2009; Castellucci, Arezes, and Viviani 2010; Castellucci, Arezes, and Molenbroek 2014a; Chung and Wong 2007; Cotton et al. 2002; Dianat et al. 2013; Gouvali and Boudolos 2006; Jayaratne and Fernando 2009; Jayaratne 2012; Panagiotopoulou et al. 2004; Parcels, Stommel, and Hubbard 1999; Tunay and Melemez 2008; Van Niekerk et al. 2013).

To avoid the mismatch problem, one the best possible solution is adjustability. Yeats (1997) argues that it is difficult to encourage proper posture early in life without the support of adjustable chairs, desks and tables in the classroom. However, scalability became a more real and cheaper solution and is somehow reflected in the increase in the number of published standards regarding school furniture in different countries, such as in Chile (INN 2002), Colombia (ICONTEC 1999), the European Union (CEN 2012), Japan (JIS 2011) and United Kingdom (BSI 2006).

As mentioned, to define the school furniture dimensions (Standard) or quantify the level of mismatch it is important to consider some students' features. For example, age is important not only due to the growth rate, but also due to the manner of growth, since before puberty the legs grow more rapidly than the trunk and in adolescents the growth spurt is largely in the trunk (Bass et al. 1999). Furthermore, students' growth seems to also be influenced by their socio-economic status. It has been observed previously that children of higher socio-economic status are, on average, taller than those of lower and medium socio-economic status (Castellucci, Arezes, and Viviani 2010). Regarding gender differences, it can be observed that until the onset of puberty, males

and females have similar rates of growth and after puberty males present the highest anthropometric values compared to females, with exceptions in some variables, such as hip width (Castellucci, Arezes, and Molenbroek 2015; Lueder and Berg Rice 2008)

As a result of the interaction between the independent variables mentioned above (school furniture design and dimension), some changes are expected to occur in a group of dependent variables, such as physical aspects and the students' performance (Figure 2.1.). As an example of this, Oxford 1969 (cited by Grimes and Legg 2004) wrote that school children are repetitively exposed to the hazards of abnormal or awkward postures due to classroom furniture that is often too big or too small. This may also affect their academic performance. Learning can also be affected, since uncomfortable and awkward body postures can decrease students' interest in learning, even during the most stimulating and interesting lessons (Hira 1980).

Regarding the physical aspects, when the Seat Height (SH) is higher than the Popliteal Height (PH) most of the students will be unable to rest their feet on the floor properly, thus causing compression of vascular and neural structures going along the popliteal space (Milanese and Grimmer 2004). However, if SH is significantly lower than PH, more than 4 cm (UNESCO 2001), this will increase the compression in the buttock region (García-Molina et al. 1992). In the case of Seat Depth (SD), the support of at least 80% of Buttock-Popliteal Length (BPL) is needed to avoid the extra pressure on the back of the thighs, which could cause discomfort (Pheasant 2003). However, the SD cannot be higher than 95% of the BPL because the student will not be able to use the backrest of the seat and, consequently, will not be able to support the lumbar spine without compression of the popliteal surface (Milanese and Grimmer 2004). To avoid this, it is likely that the students will generally move their buttocks forward toward the edge of the seat, as suggested by Panagiotopoulou et al. (2004). This improper usage of the backrest causes kyphotic posture (Khalil et al. 1993, Pheasant 1991). According to some authors (Evans, Courtney, and Fok 1988; Occhipinti et al. 1993; Orborne 1996; Oyewole, Haight, and Freivalds 2010), when students use narrow seats, they will be not be able to relieve the pressure on the buttocks and will not be able to avoid discomfort and mobility restrictions too. When students use a higher than recommended desk height, they will be forced to flex and abduct their arms, as well as elevate their shoulders. This posture may cause more muscle work load, discomfort and pain in the shoulder region (García-Molina et al. 1992). If this is the case for only one upper limb, it will result in an asymmetrical spinal posture (Zacharkow 1987).

Despite the large amount of research regarding school furniture, it is not clear if the application of the different size and/or design of school furniture improves the students' performance and physical aspects. Furthermore, Legg and Jacobs (2008) indicate that longitudinal case-controlled ergonomics intervention studies are needed if the musculoskeletal discomfort, pain and injury problems experienced by schoolchildren identified in epidemiological studies are to be addressed. Therefore, considering the developed literature review, this paper

seeks to answer the question: Does the design and/or dimension of school furniture affect the students' physical aspects and/or their performance?

2.2. Methodology

A scientific publications database, SciVerse Scopus, was used to identify the studies carried out in the field of the influence of school furniture on students' performance and physical aspects. The authors used only SciVerse Scopus since it covers a wider journal range, assisting both in keyword searches and citation analysis (Falagas 2008). The search terms used were 'school furniture', 'classroom furniture' and 'school workstations'. Inclusion criteria were established as all the reviewed articles were original studies, written in English and published between January 1980 and September 2014. The review was oriented toward the implication of the design and dimension of school furniture in students' physical aspects and their performance.

Studies that merely presented the variables but did not present any cause/effect relationship were not considered. Some examples of this are the papers by Dhara et al. (2009); Panagiotopoulou et al. (2004); Reis et al. (2012); Rudolf and Griffiths (2009) and Savanur et al. (2007). Several studies were not considered in this review since the considered sample was composed only by university students (Straker et al. 2008) and secretaries (Mandal 1991), instead of school students.

The searches resulted in a total of 581 registries (Figure 2.2.). Titles and abstracts of articles were scanned independently by the three authors to identify relevant articles to retrieve in full text. Where articles appeared potentially eligible but no abstract was available, the full text of the paper was retrieved. Disagreements between authors were referred to the other two authors, which formed a deeper analysis of the paper and a decision was then made about its inclusion. Full texts were independently reviewed for inclusion by the same three authors using a standardised data extraction form and disagreements between authors were referred to the others two authors. Primary studies meeting the inclusion criteria, which were reported in included reviews, were identified and their data extracted.

The results were grouped according to the specific dependent and independent categories (Table 2.1.). To avoid some misunderstandings, the dimension was put into an independent variable category when the mismatch level was considered (using equations or checklists) or when the school furniture was adapted to the body size of each individual child. On the other hand, dimension was not considered as an independent variable when the school furniture design proposed high furniture or stand-sit workstations without considering the students' body size or if it was not mentioned clearly in the article; in this case the independent category variable was design. Finally, design and dimension of school furniture were considered together as independent variables when the school

furniture presented a new type of design (ball chair, high furniture, slope desk or chair, stand-sit workstations, etc.) and the dimensions were adjusted to the students' anthropometric characteristics.

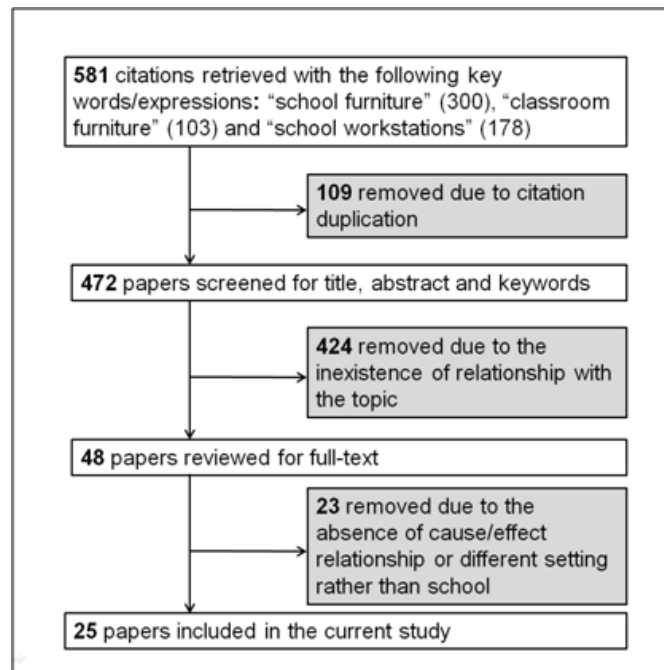


Figure 2.2. Diagram of the used search strategy and exclusion criteria

2.3. Results

Table 2.1. shows the variables considered by the 25 studies that fulfilled the inclusion criteria for this review. The design and dimension of school furniture were the most considered independent variables followed by dimension and finally design.

Before presenting the results regarding the dependent variables, it is important to mention the column with results presented in Tables 2.2. to 2.6. The impact of the independent variable was classified as (+) when it resulted in an improvement in the dependent variable, (-) when the effect was negative or no change was observed and (+/-) when the obtained results were not clear.

Considering the dependent variables, the overall results show that 64% of the reviewed studies present positive (+) results, while 24% present negative (-) or no change, with the remaining 12% of the studies showing results that were not clear (+/-). For example, from Table 2.4, the study of Benden et al. (2013) shows positive results in discomfort but negative results in posture.

Regarding the independent variables, the level of positive results are almost the same between the design and dimension, with values of 86% and 75%, respectively. However, only 40% of positive results can be seen when the reviewed studies considered had manipulated these two variables together.

Despite the fact that 25 studies were reviewed, the number of dependent variables was greater since more than half of the studies (14 out of 25) presented more than one dependent variable. The total number of dependent variables was 44, where the most studied dependent variable was the physical aspect, tested 29 times, followed by studies that presented students' performance, tested 9 times. Another dependent variable that was considered in 6 of the reviewed studies but did not fit with the categories proposed in the present review was the variable 'preference'.

In all the reviewed studies, the main research approach was quasi-experimental and experimental, observed in 10 studies each, followed by a cross-sectional study, used 5 times.

Table 2.1. Summary of the reviewed studies

	Physical aspects	Performance	Performance and physical aspects	Total
Dimension	7	1	0	8
Design	4	1	2	7
Design and dimension	6	1	3	10
Total	17	3	5	25

2.3.1. Effect of classroom furniture on students' performance

Regarding those studies that investigated effects on students' performance, only 3 studies were reviewed that met the inclusion criteria (Table 2.2.). They all used an experimental or quasi-experimental approach and the dependent variables motor skill performance, writing quality, word productivity and academic performance were equally assessed one time each.

2.3.2. Effect of classroom furniture on students' physical aspects

The impact of school furniture on the children's physical aspects was the most studied variable in the reviewed papers. Due to this and in order to fulfil the requirement of the publishing process, Tables 2.3, 2.4. and 2.5. present the synthesis of the studies according to the independent variables categories.

In Table 2.3, the most studied dependent variable was discomfort/pain. The amount of positive results included 5 out of the 7 reviewed papers.

Regarding design (Table 2.4.), 3 studies present positive results using different intervention, such as standing workstation, high furniture and tilted seat and table.

Table 2.5. resumes with the reviewed papers regarding the effect of design and dimension of classroom furniture on physical aspects. The most studied dependent variables were posture and discomfort/pain. It is also important to acknowledge that preference was considered 3 times, the same amount as the previously mentioned variables.

2.3.3. Effect of classroom furniture on students' performance and physical aspects

Concerning the studies that investigated the effect on students' performance and physical aspects (Table 2.6.), none of the reviewed studies present dimension as an independent variable. Design was considered in 2 studies and, finally, 3 studies were reviewed that met the inclusion criteria of design and dimension.

Table 2.2. Synthesis of studies referring to the effect of classroom furniture on students' performance

Independent variable	Authors (year)	Number(n), ages(yr), Country(c)	Research design	Study description	Relevant results
Dimension	Smith-Zuzovsky and Exner 2004	n: 40 yr: 6 to 7 c: USA (Maryland)	Experiment; prospective comparison	<ul style="list-style-type: none"> Two different types of school furniture were tested in a laboratory setting (A; standard, but too large school furniture, B; standard school furniture adapted to the body size of each individual child). In-hand Manipulation Test Quality section (IMT-Q) was performed for 40-45 minutes. 	+ The children who were seated in furniture that fit them well performed significantly better on the IMT-Q than those children who were seated in furniture that was too large.
Design	Schilling et al. 2003	n: 3 yr: 9 c: USA (Washington)	Single subject, A-B-A-B interrupted time series design	<ul style="list-style-type: none"> The 3 subjects with Attention Deficit Hyperactivity Disorder (ADHD) used a conventional chair during language arts throughout the baseline phases. They used therapy balls during language arts throughout the intervention phases. The entire study was 12 weeks in length; each phase was 3 weeks long. The in-seat behaviour and legible word productivity variables were tested. 	<ul style="list-style-type: none"> Results demonstrated increases in in-seat behaviour and legible word productivity for the students with ADHD when seated on therapy balls. Social validity findings indicated that generally the teacher and students preferred therapy balls.
Design and dimension	Ryan et al. 2010	n: 30 with cerebral palsy yr: 6 to 8 c: not specified	Randomized controlled trial design	<ul style="list-style-type: none"> Subjects were randomly assigned to one of two conditions. Condition 1: Q-Learn Classic school chair, with a fixed, nominal 15° forward inclined seat surface and a seat height individually adjusted. The Q-Learn desk should be individually adjusted and the surface angled downwardly toward the child at 10° from the horizontal (Mandal's parameters). The desk has a semi-circular cut out with a raised lip. Condition 2: the suboptimal standard configuration was a Virco 9000 classic series school chair, with the fixed height and height-adjustable Virco model 785 school desk. The children then performed a manual writing task and the quality of it was assessed by blind researcher using the Minnesota Handwriting Assessment (MHA) and behaviour on the seat. 	- Compared with standard school furniture, the use of specialty school furniture did not lead to immediate gains in printing legibility and other printing performance areas for children with cerebral palsy.

Table 2.3. Synthesis of studies referring to the effect of dimension classroom furniture on students' physical aspects

Independent variable	Authors	Number(n), age(yr) country (c)	Research design	Study description	Relevant results
Dimension	Batistão et al. 2012	n: 46 yr: mean 11.5 and 14.9 for 5 th and 8 th grade, respectively c: Brazil (Sao Paulo)	Cross-sectional study	<ul style="list-style-type: none"> • Anthropometric and furniture measurements were obtained from a metric tape. The criteria used to classify the adequacy of the furniture (mismatch) were based on Parcels et al. 1999. • Inclinometers were used for recording postures and movements for the head, upper back and upper arms. Also, an audiovisual record with a digital camcorder was performed. 	+ This study showed a relationship between furniture mismatch and postural overload. When the seat height is low students increase upper back left inclination and right upper arm elevation; when the seat is short students decrease the upper back flexion velocity and increase right upper arm elevation.
	Brewer et al 2009	n: 137 yr: not specified (5 th -12 th grade) c: USA (Ohio)	Cross-sectional study	<ul style="list-style-type: none"> • Anthropometric measure and school furniture dimensions were collected with an anthropometer and a tape measure. The mismatch level was calculated based on the criteria of Parcels et al. 1999. • The discomfort data of the previous month were also collected through a questionnaire. 	- Physical discomfort is not related to the degree of ergonomic mismatch. Furthermore, the significant relationship between ergonomic mismatch and body discomfort suggested a protective relationship.
	Milanese and Grimmer 2004	n: 1269 yr: 12 to 18 (8 th -12 th grade) c: Australia (Adelaide)	Cross-sectional study	<ul style="list-style-type: none"> • The ratios within each quartile for each subset of subjects (younger and older boys and girls) were calculated using the first quartile as the comparison group (best fit). • The recent reports of spinal pain (neck, thoracic and low back) and headache were extracted from a larger data set. 	+ Despite the onset of symptoms for the musculoskeletal multifactorial in nature, the school furniture certainly can play a role in the onset of symptoms in adolescents.
	Murphy et al. 2007	n: 679 yr: 11 to 14 c: England (Surrey)	Cross-sectional study	<ul style="list-style-type: none"> • The children answered a self-administered questionnaire on demographic characteristics, backache complaint history, school and leisure activities, school, general complaints and psychological factors. Also, details regarding school furniture were ascertained by the chair feature checklist. • After applying the questionnaire, logistic regression was used to assess the relationship between the variables. 	+ Properties of the school furniture, such as the chair height being too low, were significantly associated with neck and upper back pain. Also, the backrest position was associated with lower back pain, but also other factors, such as emotional problems. The results of this study suggest that inadequate school furniture can contribute to the onset of pain in schoolchildren.
	Ramadan 2011	n: 124 yr: 6 to 13 c: Saudi Arabia	Quasi-experimental design	<ul style="list-style-type: none"> • Six sets of chairs and tables were used during three different activities (reading, writing and looking at the blackboard) and were the independent variables. • The dependent variables were evaluated. Mismatch between student body dimension and classroom furniture were measured for seat height and desk height. Evaluation of back force at the 5th lumbar vertebrae and the 1st sacrum (L5/S1) as well as subjective measures of discomfort were made. 	+ Too low or too high chair and table heights relative to the students' body dimensions increased the stresses acting at L5/S1 as well as discomfort ratings. Also, the school furniture set with a better level of match presents the lowest levels of discomfort and was significantly less biomechanically stressful compared to the others for reading and looking at the blackboard.

Table 2.3. Synthesis of studies referring to the effect of dimension classroom furniture on students' physical aspects (Continued)

Independent variable	Authors	Number (n), age (yr) country (c)	Research design	Study description	Relevant results
Dimension	Skofter 2007	n: 546 subjects yr: 14 to 17 c: Denmark	Cross-sectional survey with retrospective information on complaints	<ul style="list-style-type: none"> • Low back pain (LBP) survey. Anthropometrical measurements (body height, body weight, body mass index, length of the trunk, femoral length and crural length) and measurements of the school furniture were performed. • The relationship between body dimension and dimensions of the school furniture were computed. 	- LBP occurrence was not associated with the types or dimensions of the school furniture or body dimensions.
	Straker et al. 2002	n: 33 yr: 4 to 17 c: Australia	Quasi-experimental design	<ul style="list-style-type: none"> • A 2×3×2 mixed model design was used with one within subject factor (workstation set up – standard and adjusted) and two between subject factors (age group – younger, middle and older; and gender – male and female). • Workstation set up, standard and adjusted, was used to assess the effects on the upper quadrant posture of the sagittal plane (head tilt, neck flexion, trunk flexion and gaze angle) and muscle activity was recorded from left and right of the cervical erector spine and upper trapezius muscles. 	+ The adjustments resulted in increased head tilt, neck flexion, gaze angle, cervical erector spinae activity and a trend for lower right upper trapezius activity. The recent evidence that suggests more head and neck flexion is not necessarily worse is discussed and normative values for children's head tilt and neck flexion presented.

Table 2.4. Synthesis of studies referring to the effect of design classroom furniture on students' physical aspects

Independent variable	Authors	Number(n), age(yr) country(c)	Research design	Study description	Relevant results
Design	Benden et al. 2013	n: 42 yr: 7 to 9 c: USA	Pilot study, quasi-experimental design	<ul style="list-style-type: none"> Two classrooms that contained stand-biased workstations (15 students) featured a footrest and a stool, allowing the students to sit when desired and were adjusted to each student. The other two classrooms had traditionally seated workstations (27 students). A postural analysis based on the Portable Ergonomic Observation (PEO) method was used three times at 10 minute intervals for a total of 30 minutes of observation for each student. A body part discomfort survey was applied. 	<p>- No significant difference was found between the two groups and time spent in non-preferred postures and body discomfort.</p> <p>+ The children using stand-biased workstations reported less discomfort overall.</p>
	Goncalves and Arezes 2012	n: 20 yr: 2 nd to 4 th grade (age not specified) c: Portugal	Quasi-experimental design	<ul style="list-style-type: none"> The sitting posture of the schoolchildren was video monitored during several activities, such as reading, writing and painting tasks, copying from a blackboard and working with a laptop computer. These activities were conducted during a 45 minute period using three different types of school furniture (15 minutes each): (a) traditional furniture (a flat table and chair with a 5° backward tilt), (b) a traditional chair (with a 5° backward tilt) and a table (with a 12° tilt) and (c) a chair with a seat sloped 12° forward and a table top tilted 12°. The methodology used to analyse the posture was that proposed by Murphy et al. (2002). 	<p>+ The combination (c) presents the higher percentage of observation time, with the angle tight-trunk over 90°. The same combination seems to be the most favourable for neck flexion. Despite the fact that combination (b) is the second safest combination, ninety five percent of the children expressed it as the most comfortable combination.</p>
	Hinckson et al. 2013	n: 30 yr: 10 c: New Zealand (Auckland)	Experimental design (controlled trial)	<ul style="list-style-type: none"> Two intervention classes (n: 23) received standing workstations; one control class retained usual sitting desks (n: 7). The children wore ActivPAL monitors over 7 days at baseline and during the fourth week of the intervention. Subjects completed the Nordic musculoskeletal questionnaire about musculoskeletal aches and pains. Semi-structured interviews were conducted after interventions with 2 teachers, the principal and 2 parents, as well as focus groups with 16 children. 	<p>+ A small reduction in sitting time, a very likely large increase in standing time and a very likely reduction in the number of transitions from sitting to standing for the intervention group compared to the control.</p> <p>+ The children spoke enthusiastically of the standing workstations and reported little to no musculoskeletal pain or fatigue.</p>
	Linton et al. 1994	n: 67 yr: 10 c: Sweden	Experiment; prospective comparison	<ul style="list-style-type: none"> Two classes (n: 46) were randomly assigned to the experimental group (especially "high" furniture) and one class (n: 21) served as a control group (standard furniture). In both groups, two questionnaires regarding different issues such as posture, comfort furniture, school interest and health problems were completed. Sitting behaviour was observed twice before and after the intervention as well as at a five-month follow-up periods. 	<p>+ The high furniture type was evaluated positively by the children and the group of children who sat on it experienced less back, neck, headache and fatigue than the control group.</p> <p>+/- However, their posture did not improve. One half of the children improved their attitudes hugely, the other half did not.</p>

Table 2.5. Synthesis of studies referring to the effect of design and dimension classroom furniture on students' physical aspects

Independent variable	Authors	Number(n), age(yr) country(c)	Research design	Study description	Relevant results
Design and dimension	Aagaard-Hansen and Storr-Paulsen 1995	n: 144 yr: 7 to 11 c: Denmark	Experimental, prospective comparison	<ul style="list-style-type: none"> In the first phase, the 144 children had almost identical school furniture. In the second phase, according to a random allocation, the children received one of the three different types of school furniture (Type A: standard height, horizontal work surface; Type B: taller chair, forward sloping seat, adjustable desk height, slanted work surface; Type C: standard height, slanted work surface). The authors were present in order to explain the correct use of the new furniture and to make sure that it was adapted to the individuals. All of the children were interviewed twice about the comfort of the furniture and the level of pain using a structured questionnaire. The test duration was about 1 month. 	<ul style="list-style-type: none"> No difference was found in perceived physical complaints. + Type B was evaluated as being significantly better than Types A and C regarding reading position, table height, back-rest, chair height and global comparison. + Slanted desk-top surface was perceived to be significantly positive, independent of the height of the furniture (Type B and C).
	Saarni et al. 2007	n: 97 yr: mean 12 and 14 for 6 th and 8 th grade, respectively c: Finland	Quasi-experimental design	<ul style="list-style-type: none"> Students were followed for one year. The intervention group/school (n: 47) received a new workstation (adjustable height saddle-type chairs with wheels and adjustable desks with comfort curve for the body). The control group/school (n: 50) continued using their conventional workstations. Some workstations were adjustable by height and desk slope. Working postures were analysed using modified OWAS for a part of each group (n = 21, both groups), by means of video recording at baseline, before new workstations were introduced and during follow-up. 	<ul style="list-style-type: none"> + There was a significant increase in upright back and neck postures in the intervention group compared to controls during follow-up. The saddle-type chairs allowed significantly greater trunk-thigh angles among participants compared to conventional chairs. + Using individually adjustable saddle-type chairs and desks improved working postures compared to the use of conventional workstations.
	Saarni et al. 2009a	n: 43 yr: mean 12 and 14 for 6 th and 8 th grade, respectively c: Finland	Quasi-experimental design	<ul style="list-style-type: none"> Students were followed for 26 months. The intervention group/school (n: 23) received new workstations (adjustable height saddle-type chairs with wheels and adjustable desks with comfort curve for the body) and the match was ensured by regular adjustments on average once every 2 months. The control group/school (n: 20) continued using their conventional workstations; some workstations were adjustable by height and desk slope. Musculoskeletal strain was gathered using the modified Borg scale once a day over one school week. Musculoskeletal pain was assessed through a self-administered questionnaire using VAS. 	<ul style="list-style-type: none"> - No difference was found in physical symptoms between the control and intervention groups. However, the intervention group reduced exposure to ergonomic furniture by half.

Table 2.5. Synthesis of studies referring to the effect of design and dimension classroom furniture on students' physical aspects (Continued)

Independent variable	Authors	Number(n), age(yr) country(c)	Research design	Study description	Relevant results
Design and dimension	Saarni et al. 2009b	n: 43 yr: mean 12 and 14 for 6 th and 8 th grade, respectively c: Finland	Quasi-experimental design	<ul style="list-style-type: none"> Students were followed for two years. The intervention group/school (n: 26) received a new workstation (adjustable height saddle-type chairs with wheels and adjustable desks with comfort curve for the body) and the match was ensured by regular adjustments on average once every 2 months. The control group/school (n: 21) continued using their conventional workstations; some workstations were adjustable by height and desk slope. Spine positions and mobility were analysed (using a digital goniometer) 4 times, one before new workstations were introduced and 3 times during the follow-up. Also, preference was assessed through a self-administered questionnaire using the visual analogue scale. 	<p>- Lumbar lordosis, thoracic kyphosis and lumbar and sacral mobility did not differ between the intervention and control groups during the 24 month follow-up. However, in both groups the intra-group 12 and 24 month follow-up was statistically significant regarding time effects.</p> <p>+/- New workstations were considered significantly better compared to the conventional workstation during the first 12 month follow-up. However, the effect was temporary and no difference was seen between the two groups in the second 12 month period.</p>
	Schröder 1997	n: 257 subjects yr: 7 to 9; 15 to 17 c: Germany (Kiel)	Quasi-experimental design; prospective comparison	<ul style="list-style-type: none"> Two different types of school furniture were tested. The "standardized school furniture" with different size variations for different body sizes and the "non-standardized school furniture" with a higher seat and desk, equipped with a horizontal bar serving as a foot rest. Also, the seat is made up of two parts: a horizontal rear part and a front part with a slanting angle of 15°. The variable "posture" was assessed by the classification of the movements and postures on the basis of a catalogue of 45 minutes per child. 	<p>- The "non-standardized school furniture" children showed less variation in foot movement. Especially with younger children, certain extreme postures were significantly less often assumed due to the type of furniture limits and the opportunities to interrupt monotonous permanent postures.</p> <p>Furthermore, the results suggest that the "standardized school furniture" allows for a greater variety of postures.</p>
	Troussier 1999	n: 263 yr: 8 to 11 c: France	Case-control study, retrospective comparison	<ul style="list-style-type: none"> 4 or 5 years using one of these two different types of school furniture: the "ISO standard furniture" with only one size (n: 125) and "Mandal's furniture" which was adjusted each year according to the body size of the children. All of the children answered a self-administered questionnaire regarding a subjective assessment of the furniture as well as physical complaints since the beginning of primary school and the point prevalence within the previous week. Physical examination was made and was focused on scoliosis, kyphosis and stiffness of the hamstrings and lower back. 	<p>- There were no significant differences in physical symptoms (pain) between the two groups.</p> <p>- Also, the physical examination showed no differences between the two groups.</p> <p>+ However, "Mandal's furniture" scored better at writing posture and comfort.</p>

Table 2.6. Synthesis of studies referring to the effect of classroom furniture on students' performance and physical aspects

Independent variable	Authors	Number(n), age(yr) country (c)	Research design	Study description	Relevant results
Design	Benden et al. 2011	n: 58 yr: 4 th grade (age not specified) c: USA (Texas)	Prospective experimental study	<ul style="list-style-type: none"> • The 2 treatment classrooms were converted into stand-sit workstations with stools, whereas the control classrooms remained unaltered for the entire school year. • Students were monitored with calorie expenditure measuring Body-Bugg armbands worn for 10 days in the fall and spring. 	<ul style="list-style-type: none"> + Students in the treatment group burned 17% more calories than did those in the control group. + Interviews with teachers and parents of the students in the treatment group indicated a positive effect on child behaviour and classroom performance.
	Blake et al. 2012	n: not specified yr: 6 to 7 c: USA (Texas)	Quasi-experimental pilot study	<ul style="list-style-type: none"> • Before the start of the fall semester, the 2 treatment classrooms were outfitted with stand/sit workstations and stools, and the third classroom was outfitted before the start of spring semester. The 2 control classrooms remained outfitted with the conventional furniture. Students were assessed 4 times throughout the school year. • Each student in the control and treatment groups was outfitted with a Body-Bugg to measure caloric expenditure for 5 consecutive days. 	<ul style="list-style-type: none"> + The stand/sit workstations increase passive calorie burn compared to regular workstations. + The study also revealed possible behavioural effects related to students' attention and behaviour in the classroom.
Design and dimension	Knight and Noyes 1999	n: 21 yr: 9 to 10 c: UK	Experimental design	<ul style="list-style-type: none"> • Repeated measure design was used with the children's on-task and sitting behaviour observed over a 2 week period with their original classroom furniture, and then with their new furniture for a further 2 weeks (chair and table 2000). The new chair provided a seat that sloped slightly back but with a somewhat deeper and shallower curving front edge than older conventional seating, and introduced a protruding back support approximately halfway up the rigid back of the chair. • Three observers were instructed in the criteria for "on-task/off-task" and "standard/non-standard sitting" behaviour (defined according to whether the feet were placed on the floor in front of the chair). • A structured interview format was used for collecting information on individual children about comfort, preferred sitting positions and back pain using 5-point Likert scales. In addition, children were asked their preferences for chair design by sitting on the three chairs and then ranking them for comfort. 	<ul style="list-style-type: none"> + The children showed a modest but significant improvement in on-task behaviour following the introduction of the newly designed furniture. + The chair and table 2000 resulted in a highly significant reduction in non-standard sitting behaviour. The popliteal/seat height relationship suggests peaks of non-standard sitting when popliteal height is either a few centimetres less than seat height or when it is in excess of 5 cm. The greater the seat depth compared to upper leg length, the less likely the child will be able to make effective use of the back rest. +/- Chair preference was mixed; attitudes toward chair 2000 were rather polarized. The children either liked it "best" or "least of all".

Table 2.6. Synthesis of studies referring to the effect of classroom furniture on students' performance and physical aspects (Continued)

Independent variable	Authors	Number(n), age(yr) country (c)	Research design	Study description	Relevant results
Design and dimension	Koskelo et al. 2007	n: 30 yr:16 to 18 c: Finland	Quasi-experimental design, prospective comparison	<ul style="list-style-type: none"> • A comparison of the effects over 24 months of two types of school furniture. Control group: old non-adjustable traditional standard horizontal school desks and horizontal chairs. Intervention Group: adjustable saddle chair without backrest and 5 wheels. The desk was adjustable and could be tilted. • Assessment of posture, trunk muscle activity and strength, pain, furniture preference and academic performance. 	<ul style="list-style-type: none"> + Intervention group of students' sitting postures standing kyphosis, scoliosis and lordosis became significantly better, both before and after growth cessation. + Trunk muscle strength increased in intervention students whose muscle tension during classes fell significantly in the trapezius, whereas in the control students, lumbar tension increased. + The neck-shoulder pains significantly decreased in both groups, but more in the intervention group. + Intervention students reported that they experienced benefits from the adjustable tables and chairs. They also received significantly better overall marks.
	Wingrat and Exner 2005	n: 63 yr: 8 to 9 c: USA (Baltimore)	Experimental pilot study	<ul style="list-style-type: none"> • Three groups of fourth grade students were observed during their math class (55 minutes), four times in each of three conditions. The baseline condition consisted of a large chair and desk. The first intervention condition involved the same configuration as the original furniture but with the original furniture replaced with new appropriate-sized furniture. Furthermore, the desks presented a slight concave curve in the front and the chairs featured a convex and flexible back support. In the second intervention condition, the new furniture was placed in horizontal rows facing the front of the classroom. • The dependent variables were on-task and sitting behaviours using a checklist and observation form called Observing Pupils and Teachers in Classrooms (OPTIC). This instrument considered the position of the pelvis, feet, trunk, forearms and arms. 	<ul style="list-style-type: none"> + The children demonstrated better sitting and task behaviours when seated in the furniture of the intervention condition (it fit them better and presented convex and flexible back support). + Also, the same results were shown for task behaviours.

2.4. Discussion

The purpose of this study was to assess, through a critical review, if school furniture characteristics, specifically dimensions and design, have an impact on students' performance and/or on some of their physical aspects, such as posture, reported pain, discomfort or other similar physical conditions. After reviewing the 25 papers selected according to the defined criteria, it seems that there are some positive signs since 68% of the reviewed papers present positive results. These results are in accordance with the review from Grimes and Legg (2004), who have examined the literature on school student posture in classroom environments and indicated that student posture, anthropometrics and furniture; computer use; pain reporting; and vision may influence the prevalence of musculoskeletal disorders among those students. However, these results are different from those presented by Yeats (1997), where only the effectiveness of ergonomic school furniture on schoolchildren has been demonstrated in just one study reviewed. One possible explanation for this difference could be the fact that 23 out of the 25 reviewed papers in the current study were published after 1997.

Contextual factors varied greatly across the studies reviewed. However, the primary reason for engaging in this research was to determine if school furniture has an impact on the wellbeing of children – in the way of scholastic performance or related measures or in their physical characteristics, such as the ones referred to above. In this section, the main review findings are discussed separately by each dependent variable, i.e. the effects on students' performance, the effects on physical aspects and the effects on performance and physical aspects together.

It has come to the attention of the authors that the diverse nature and the variables used in the studies reviewed were very different, even testing similar variables, and that both approaches can have their strengths and weaknesses. Some features of the studies are also discussed for each dependant variable.

2.4.1. Effects on students' performance

Two out of three studies concluded that performance was improved when students were seated in different conditions than 'normal' school furniture, while the third did not find any changes. The positive results were obtained when the dimension (Smith-Zuzovsky and Exner, 2004) and design (Schilling et al. 2003) independent variables were manipulated. A common particularity found in two of these papers was that the analysed population was composed by kids with behavioural (ADHD) (Schilling et al. 2003) or neurological problems (Cerebral Palsy) (Ryan, Rigby, and Campbell 2010), thus the findings may have been affected by their different physiology or sensitivity. In the case of the study from Ryan et al. (2010), the results show no differences in legible word productivity when the design and dimension variables were manipulated. Contrary to these results,

Parush et al. (1998) concluded that ergonomics factors, such as sitting posture and positioning are important factors in handwriting performance.

The two studies that found an impact on performance presented a significant difference between the considered samples, not only due to the type but also due to the number of participants. Schilling et al. (2003) used only 3 subjects with ADHD seated on therapy ball. Because the sample is small and uses different physiology or sensitivity, the results should still be read with caution. Furthermore, one may hypothesize that the therapy ball would facilitate "dynamic sitting" due to children with ADHD increasing in-seat behaviour. However, the study by Kingma and van Dieën (2009), with a sample of 10 females, shows that the beneficial effects of more dynamics due to sitting on an exercise ball are questionable as far as the spine is concerned. Furthermore, the advantages with respect to the physical loading of sitting on an exercise ball may not outweigh the associated disadvantages.

It was observed through the review performed to conduct this study that not many authors have focused on the impact that school furniture characteristics may have on school activity performance, especially using large samples, with the exception of Smith-Zuzovsky and Exner (2004). There are some reasons for this situation. First, it can be difficult to get all teachers to participate. Another factor that could reduce the validity of these studies is the several extraneous variables associated with school activity performance, which may also influence the results, such as the well-known Rosenthal and Hawthorne effects as well as socioeconomic and psychological factors, which may also affect pain perception (Murphy, Buckle, and Stubbs 2007). Finally, another reason could be the one reported by Koskelo et al. (2007), who stated that the kind of studies with physiological and other follow-up measurements are only possible in small schools since, for example, the Finnish curricula today have many elective subjects, which are taught in specialized classrooms. The students in large schools must usually move several times per day to different classrooms, which very often are located in different buildings. This situation is corroborated by the studies of Saarni et al. (2009a).

In the future, it would be interesting to see long-term prospective studies that could assess performance associated with the use of new and improved furniture in school populations, assessing students' performance as well as some behavioural issues.

2.4.2. Effects on physical aspects

The impact of school furniture on children's physical aspects was the most studied variable in the reviewed papers. Physical aspects refer to characteristics such as discomfort/pain, electromyography (EMG), energy expenditure and posture, which were studied either as the whole body or a specific body segment (i.e. trunk, neck, head and legs). Considered in Tables 2.3. to 2.6, the most studied dependent variable related to physical aspects, were posture and discomfort/pain, assessed 12 times, followed by energy expenditure and EMG,

studied 2 times and, finally, physical examination, which was assessed once. Posture assessment techniques were usually performed using observational analysis through video recordings, which later were analyzed using postural analysis methods or biomechanical strain criteria, such as joint angles.

With just a few exceptions, such as the work of Brewer et al. (2009) and Skoffler (2007), most all of the studies reviewed found that a change in school furniture dimensions (better fit or match) resulted in an improvement in posture, EMG and discomfort/pain (Table 2.3.). However, Skoffler (2007) notes that "the idea function limiting LBP was positively associated with sitting on an adjustable chair at school. Using an adjustable chair as a cause of LBP is not probable. Rather the explanation of this finding could be that the schoolchildren most bothered by pain had requested or had been offered an adjustable chair". However, another explanation that could change the results and was not considered by the author is as follows: did the students know how to adjust the school furniture? This is very important since students do not automatically sit properly in the ergonomically designed furniture, they need proper instructions and adjustment (Linton et al. 1994).

The positive overall results obtained when the school furniture dimension fit the students' anthropometric measure (6/8 studies) made it obligatory to pay closer attention to the students anthropometric characteristics and to use adjustable furniture with proper instructions. However, implementing adjustable chairs and tables within every classroom is an expense that many school budgets may not be able to assume (Shinn et al. 2002). Since adjustability could be an expensive solution, scalability using school furniture standards became a cheaper solution. Furthermore, to avoid the high level of mismatch the school furniture standards need to be updated over time due to the positive secular trend (Castellucci et al. 2014b).

Regarding design and physical aspects, 3 out 4 of the reviewed studies presented positive results. The modification of table and chair tilt presented positive results (Gonçalves and Arezes 2012). This is reinforced by the study presented in Table 2.5. from Aagaard and Storr-Paulsen (1995). Also, the idea of high furniture and standing workstations seems to present benefits regarding discomfort/pain. Furthermore, the standing workstation results could be supported by the fact that being seated for a long period of time on school furniture is being associated with reports of musculoskeletal discomfort and pain (Fallon and Jameson 1996).

The 4 reviewed studies (Benden et al. 2013, Gonçalves and Arezes 2012, Hinckson et al. 2013, Linton et al. 1994) have some weaknesses that could have contributed to those results; thus, a small sample size, no random allocation of participants to experimental groups, a small observation time and lack of training on proper posture criteria were required.

Concerning studies referring to the effect of the design and dimension of classroom furniture on physical aspects (Table 2.5.), they were expected to have high levels of positive results since design and dimension did it independently. However, only one of the reviewed studies presented positive results. One explanation could be that 3 out of 6 of the reviewed studies came from the same authors, Saarni et al. (2009a, 2009b, 2007) and the

study description was almost the same (Table 2.5.). Only one of the mentioned studies presents positive results regarding posture, using OWAS for the evaluation. On the other hand, the variables discomfort, posture (digital goniometer), preference and musculoskeletal strain did not present differences between the two studied conditions. It is important to notice that the 3 studies shared the same limitations, which can affect the results, together with no random allocation of intervention, high experimental dropout and reduced exposure to ergonomic furniture in the intervention group due to teaching arrangements. Finally, a very important issue was that these authors advised the participants not to self-adjust the furniture in order to avoid a conflict between anthropometrics and workstations. The matches between the elbow-floor height and the desk height and those between the trunk-thigh angle and the chair height of each participant were checked on average every 2 months. The study from Schröder (1997) concluded that the furniture with a higher seat and desk, equipped with a horizontal bar serving as a foot rest, allowed less variation of posture, a condition that is identified as a risk factor for lower back pain (Kumar and Mital 1992).

2.4.3. Effects on both students' performance and physical aspects

Only 2 studies from the same group of authors (Benden et al. 2011, Blake, Benden, and Wendel 2012) took a different approach, which was to assess the impact of furniture in energy expenditure. They tested to see if the use of sit to stand school furniture caused an increase in caloric consumption. Both studies found a significant impact when using furniture different from that which is traditionally assigned to children, specifically those that encouraged stand-sit with stools. The authors also indicated that a positive effect was observed in child behaviour and classroom performance. However, it is important to mention that no objective tool was used to assess students' performance.

There are only 3 studies that present the four categories of variables. These studies point to a more comprehensive point of view of school furniture studies, since they take into account both the physical as well as the academic impact that school furniture can have on students, thus contributing to focus and assessing interventions in a more holistic and structured way.

All the studies present positive results but different intervention design. Koskelo et al. (2007) used an adjustable saddle chair and a desk adjustable in height and tilt. This furniture follows the principles of Mandal presented early in the introduction section. The only limitation of the study was that there was no random allocation of participants to either control or experimental groups.

Wingrat and Exner (2005) indicated that the experimental chairs were advantageous to the students for at least two reasons: (1) they were smaller so the students could put their feet on the floor and (2) they were designed to support the curvature of the students' spine via the convex back rest, which then allowed for a more neutral pelvic position. The second reason can be, in some ways, contradictory to the opinion of Bendix et al. (1996) ,

who indicated that the backrest may facilitate the forward movement of the buttocks and kyphosis of the lumbar spine to stabilize the trunk against the backrest. Mandal (1982) also argued that the need for lumbar support is one of the four fallacious design principles of sitting.

The featured principles regarding design need to enforce the changes of postures (Dynamic Sitting) from sit to stand and through half-standing positions. To complete this mission, the desk will have a tilt angle, a slight concave curve in the front and an adjustable height. A high saddle chair would be desirable; however, both feet must be on the floor and without a foot rest in order to avoid less variation of posture presented in the study of Schröder (1997). If the saddle chair is not possible, the seat must be presented in two parts: (1) the rear part being horizontal and (2) the front part slanting at an angle of 15°. This type of seat is similar to the one used by the University of Nottingham. It presents a series of advantages, including decreased spinal loading and reduced discomfort (Corlett and Gregg 1994).

Finally, as mentioned in the introduction and presented previously by Grimes and Legg (2004), the improvement of school working conditions should include an integrated ergonomics approach involving micro and macro ergonomic factors. However, the results from this review are supportive of the conclusions that classroom furniture design and dimension are key factors, not only for physical aspects but also for students' performance.

2.5. Limitations Of This Review

A probable limitation of this review includes the search process itself, which may not have allowed the identification of all studies showing the effect of the design and/or dimension of school furniture in students' physical aspects and/or on their performance. The wide variety of research approaches adopted by the studies reviewed also made it difficult to summarize and obtain relevant findings for some topics like performance, where subjective methods were mostly used to analyse the corresponding effect.

2.6. Conclusion

The results of the review provide a clearer picture regarding one of the school micro-ergonomics variables. Twenty-five studies considering the impact of school furniture design and/or dimension characteristics in the students' performance and physical aspects were reviewed.

Concerning the studies that have only tested school performance, 2 out of 3 presented positive results. Those findings should be considered with caution, mainly because of the small size samples used and the participants' characteristics, which included participants with either behavioural or neurological issues.

Within the studies that assessed children's physical aspects, most studies reviewed found that a change in school furniture dimensions resulted in an improvement in posture, EMG and discomfort/pain, with the latter being the most studied dependant variable. Proper care should be taken when using adjustable furniture, since a lack of knowledge regarding proper settings and/or out of date standards may contribute to negative effects.

Only 5 studies analysed the effects on both students' performance and physical aspects. All of them found positive relevant results, specifically an increase in energy expenditure and better academic performance in class behaviour and attention span.

From the overall results, there are some school furniture findings that need to be highlighted: the school furniture must fit student anthropometric characteristics, the desk must have the possibility of a tilt angle and a slight concave curve in the front, with a high saddle chair also desirable. If it is not possible, the seat must be presented in two parts: (1) the rear part being horizontal and (2) the front part slanting at an angle of 15°.

When reviewing the considered papers, a significant focus on assessing the effects of school furniture on physical aspects was observed. When studying the effect on performance or both physical aspects and performance, just a few studies were found. Further research should be performed, which should target the detailed study of those aspects regarding the dependent variables, specifically by using more objective measures, such as academic performance complemented with controlled and prospective design, which will ultimately allow for the positive effect of school furniture on performance to be determined more clearly.

References

- Aagaard, J., and A. Storr-Paulsen.1995. "A comparative study of three different kinds of school furniture." *Ergonomics* 38 (5): 1025–1035.
- Agha, S. R. 2010. "School furniture match to students' anthropometry in the Gaza Strip." *Ergonomics* 53 (5): 344–354.
- Bass, S., P. D. Delmas, G. Pearce, E. Hendrich, A. Tabensky, and E. Seeman. 1999. "The differing tempo of growth in bone size, mass and density in girls is region-specific." *Journal of Clinic Investigation* 104 (6): 795–804.
- Batistão, M. V., A. C. Sentanin, C. S. Moriguchi, G. Hansson, H. J. C. Coury, and T. Sato. 2012. "Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs." *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1): 4817-4824.
- Benden, M. E., J. J. Blake, M. L. Wendel, and J. C. Huber. 2011. "The impact of stand-biased desks in classrooms on calorie expenditure in children." *American Journal of Public Health* 101 (8), 1433–1436.

- Benden, M. A., E. Pickens, J. Shipp, J. Perry, and D. Schneider. 2013. "Evaluating a school based childhood obesity intervention for posture and comfort." *Health* 05 (08), 54–60.
- Bendix, T., V. Poulsen, K. Klausen, and C. Jensen. 1996. "What does a backrest actually do to the lumbar spine?" *Ergonomics* 39 (4): 533–542.
- Blake, J., M. Benden, and M. Wendel. 2012. "Using stand/sit workstations in classrooms: lessons learned from a pilot study in Texas." *Journal of Public Health Management Practice* 18 (5): 412–5.
- Brewer, J. M., K. G. Davis, K. K. Dunning, and P. A. Succop. 2009. "Does ergonomic mismatch at school impact pain in school children?" *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4): 455–464.
- BSI (British Standard Institution). 2006. BS EN 1729-1: 2006 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions. UK: BSI.
- Bruin de, R., and J.F.M. Molenbroek. 2010. "The negative effects of obsolescent schoolfurniture on the physical development of students and their performance." Literature study report commissioned by the Dutch Society of Schoolfurniture Manufacturers.(In Dutch). *Erin Ergonomie en Industrieel Ontwerp*, Delft University of Technology.
- Castellucci, H. I., P. M. Arezes, and C. A. Viviani. 2010. "Mismatch Between Classroom Furniture and Anthropometric Measures in Chilean Schools." *Applied Ergonomics* 41 (4): 563–568.
- Castellucci, H.I., P. M. Arezes, and J.F.M. Molenbroek. 2014a. "Applying different equations to evaluate the level of mismatch between students and school furniture." *Applied Ergonomics*, 45(4), 1123–32.
- Castellucci, H.I., P. M. Arezes, J.F.M. Molenbroek and C. Viviani. 2014b. "The effect of secular trends in the classroom furniture mismatch support for continuous update of school furniture standards." *Ergonomics*, DOI: <http://dx.doi.org/10.1080/00140139.2014.978900>
- Castellucci, H.I., P. M. Arezes, and J.F.M. Molenbroek. 2015. Analysis of the most relevant anthropometric dimensions for school furniture selection based on a study with students from one Chilean region. *Applied Ergonomics*, 46PA, 201–211.
- CEN (European committee for standardization). 2012. PREN 1729-1: Furniture - Chairs and Tables for Educational Institutions - Part 1: Functional Dimensions. Brussels: CEN
- Chung, J. W. Y., and T. K. S. Wong. 2007. "Anthropometric evaluation for primary school furniture design." *Ergonomics* 50 (3): 323–334.
- Corlett, E. N. and H. Gregg. 1994. Seating and access to work. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. London: Taylor & Francis.
- Cotton, L. M., D. G. O'Connell, P. P. Palmer, and M. D. Rutland. 2002. "Mismatch of school desks and chairs by ethnicity and grade level in middle school." *Work: A Journal of Prevention, Assessment & Rehabilitation* 18 (3): 269–280.

- Dhara, P. C., G. Khaspuri, and S. K. Sau. 2009. "Complaints arising from a mismatch between school furniture and anthropometric measurements of rural secondary school children during classwork." *Environmental Health and Preventive Medicine* 14 (1): 36–45.
- Dianat, I., M. Ali Karimib, A. Asl Hashemic, and S. Bahrapour. 2013. "Classroom furniture and anthropometric characteristics of Iranian high school students: Proposed dimensions based on anthropometric data." *Applied Ergonomics* 44 (1): 101–108.
- Evans, W. A., A. J. Courtney, and K. F. Fok. 1988. "The design of school furniture for Hong Kong school children: an anthropometric case study." *Applied Ergonomics* 19 (2): 122-134.
- Falagas, M. E., E. I. Pitsouni, G. Malietzis, and G. Pappas. 2008. "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses." *FASEB Journal: Official Publication of the Federation of American Societies for Experimental Biology* 22 (2): 338–42.
- Fallon, E., and C. Jameson. 1996. An ergonomic assessment of the appropriateness of primary school furniture in Ireland. In: Ozok, A.F., and Salvendy, G (Eds.), *Advances in Applied Ergonomics*. USA: West Lafayette.
- García-Molina, C., R. Moraga, L. Tortosa, and V. Verde. 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico [Ergonomic Furniture Design Recommendations]*. Valencia: Instituto Biomecánico de Valencia.
- Gonçalves, M. A., and P. M. Arezes. 2012. "Postural assessment of school children : an input for the design of furniture." *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1): 876–880.
- Gouvali, M. K., and K. Boudolos. 2006. "Match between school furniture dimensions and children's anthropometry." *Applied Ergonomics* 37 (6): 765-773.
- Grimes, P., and S. Legg. 2004. "Musculoskeletal disorders (MSD) in school students as a risk factor for adult MSD: a review of the multiple factors affecting posture, comfort and health in classroom." *Journal of the Human-Environmental System* 7 (1): 1–9.
- Hinckson, E., S. Aminian, E. Ikeda, T. Stewart, M. Oliver, S. Duncan, and G. Schofield. 2013. "Acceptability of standing workstations in elementary schools: a pilot study." *Preventive Medicine* 56 (1): 82–5.
- Hira, D. S. 1980. "An ergonomic appraisal of educational desks." *Ergonomics* 23 (3): 213–221.
- ICONTEC (Instituto Colombiano de Normas Técnicas y Certificación). 1999. Norma Técnica Colombiana 4641. Muebles Escolares. Pupitre con Silla para Aulas de Clase. Bogotá: ICONTEC.
- INN (Instituto Nacional de Normalización Chile). 2002. Norma Chilena 2566. Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales [Chilean Standard 2566. School Furniture - School Chairs and Tables - Dimensional Requirements]. Santiago: INN.

- Jayaratne, I. L. K., and D. N. Fernando. 2009. "Ergonomics related to seating arrangements in the classroom : Worst in South East Asia ? The situation in Sri Lankan school children." *Work: A Journal of Prevention, Assessment & Rehabilitation* 34: 409–420.
- Jayaratne, K. 2012. "Inculcating the Ergonomic Culture in Developing Countries: National Healthy Schoolbag Initiative in Sri Lanka." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54 (6): 908-924.
- JIS (Japanese Industrial Standards). 2011. JIS S 1021. School furniture – Desks and chairs for general learning space. Tokyo: JIS.
- Khalil, T. M., E. M. Abdel-Moty, R. S. Rosomoff, and H. L. Rosomoff. 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. New York: Van Nostrand Reinhold.
- Kingma, I., and J. van Dieën. 2009. "Static and dynamic postural loadings during computer work in females: Sitting on an office chair versus sitting on an exercise ball." *Applied Ergonomics* 40 (2): 199–205.
- Knight, G. and J. Noyes. 1999. "Children's behaviour and the design of school furniture." *Ergonomics* 42 (5): 747–760.
- Koskelo, R., K. Vuorikari, and O. Hänninen. 2007. "Sitting and standing postures are corrected by adjustable furniture with lowered muscle tension in high-school students." *Ergonomics* 50 (10): 1643–1656.
- Kumar, S., and A. Mital. 1992. "Margin of safety for the human back: a probable consensus based on published studies." *Ergonomics* 35 (7,8), 769–781.
- Legg, S., and K. Jacobs. 2008. "Ergonomics for schools." *Work: A Journal of Prevention, Assessment and Rehabilitation* 31, 489–493.
- Linton, S. J., L. Hellsing, T. Halme, and K. Akerstedt. 1994. "The effects of ergonomically designed school furniture on pupils' attitudes, symptoms and behaviour." *Applied Ergonomics* 25 (5): 299–304.
- Lueder, R., and V. Berg Rice. 2008. *Ergonomics for children*. London: Taylor & Francis.
- Mandal, A. 1981. "The seated man (Homo Sedens). The seated work and practice position. Theory." *Applied Ergonomics* 12 (1): 19–26.
- Mandal, A. 1982. "The correct height of school furniture." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 24 (3): 257–269.
- Mandal, A. 1991. "Investigation of the lumbar flexion of the seated man." *International Journal of Industrial Ergonomics* 8 (1): 75–87.
- Mandal, A. 1994. The prevention of back pain in school children. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. London: Taylor & Francis.
- Milanese, S., and K. Grimmer. 2004. "School furniture and the user population: an anthropometric perspective." *Ergonomics*, 47 (4): 416–426.

- Murphy, S., P. Buckle, and D. Stubbs. 2002. "The use of the portable ergonomic observation method (PEO) to monitor the sitting posture of schoolchildren in the classroom." *Applied Ergonomics* 33 (4): 365–370.
- Murphy, S., P. Buckle, and D. Stubbs. 2007. "A cross-sectional study of self-reported back and neck pain among English schoolchildren and associated physical and psychological risk factors." *Applied Ergonomics* 38 (6): 797–804.
- Occhipinti, E., D. Colombini, G. Molteni, and A. Grieco. 1993. "Criteria for the ergonomic evaluation of work chairs." *Le Medicina Del Lavoro* 84 (4): 274–285.
- Orborne, D. J. 1996. *Ergonomics at Work: Human Factors in Design and Development*. 3rd edition. Chichester: John Wiley & Sons.
- Oyewole, S. A., J. M. Haight, and A. Freivalds. 2010. "The ergonomic design of classroom furniture/computer work station for first graders in the elementary school." *International Journal of Industrial Ergonomics* 40 (4): 437–447.
- Panagiotopoulou, G., K. Christoulas, A. Papanickolaou, and K. Mandroukas. 2004. "Classroom furniture dimensions and anthropometric measures in primary school." *Applied Ergonomics* 35 (2): 121–128.
- Parcells, C., M. Stommel, and R.P. Hubbard. 1999. "Mismatch of classroom furniture and student body dimensions." *Journal of Adolescent Health* 24 (4): 265–273.
- Parush, S., N. Levanon-Erez, and N. Weintraub. 1998. "Ergonomic factors influencing handwriting performance." *WORK A Journal of Prevention, Assessment & Rehabilitation* 11(3): 295–305.
- Pheasant, S. 1991. *Ergonomics, Work and Health*. Hong Kong: Macmillan.
- Pheasant, S. 2003. *Bodyspace*. 2nd edition. London: Taylor & Francis.
- Ramadan, M. Z. 2011. "Does Saudi school furniture meet ergonomics requirements?" *Work: A Journal of Prevention, Assessment & Rehabilitation* 38 (2): 93–101.
- Reis, P., and R. Moro, J. L. Da Silva, L. Paschoarelli, F. Nunes Sobrinho, and L. Peres. 2012. "Anthropometric aspects of body seated in school." *Work: A Journal of Prevention, Assessment and Rehabilitation* 41 (1): 907–14.
- Rudolf, M., and Y. Griffiths. 2009. "Evaluating the ergonomics of a student learning environment." *Work: A Journal of Prevention, Assessment and Rehabilitation* 34 (4): 475–480.
- Ryan, S. E., P. J. Rigby, and K. Campbell. 2010. "Randomised controlled trial comparing two school furniture configurations in the printing performance of young children with cerebral palsy." *Australian Occupational Therapy Journal* 57 (4): 239–245.
- Saarni, L., C. H. Nygård, A. Rimpelä, T. Nummi, and A. Kaukiainen. 2007. "The working postures among schoolchildren—a controlled intervention study on the effects of newly designed workstations." *The Journal of School Health* 77 (5): 240–247.

- Saarni, L., A. Rimpela, T. Nummic, A. Kaukiainen, and J. Salminen. 2009a. "Do ergonomically designed school workstations decrease musculoskeletal symptoms in children? A 26-month prospective follow-up study." *Applied Ergonomics* 40 (3): 491–499.
- Saarni, L., C. H. Nygård, T. Nummi, A. Kaukiainen, and A. Rimpelä. 2009b. "Comparing the effects of two school workstations on spine positions and mobility, and opinions on the workstations - A 2-year controlled intervention." *International Journal of Industrial Ergonomics* 39 (6): 981–987.
- Savanur, C. S., C. R. Altekar, and A. De. 2007. "Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions." *Ergonomics* 50 (10): 1612-1625.
- Schilling, D. L., K. Washington, F. F. Billingsley, and J. Deitz. 2003. "Classroom seating for children with attention deficit hyperactivity disorder: therapy balls versus chairs." *The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association* 57 (5): 534–41.
- Schröder, I. 1997. "Variations of sitting posture and Physical Activity in Different Types of School Furniture." *Coll Antropol* 21 (2): 397–403.
- Shinn, J., K. Romaine, T. Casimano, and K. Jacobs. 2002. "The effectiveness of ergonomic intervention in the classroom." *WORK: A Journal of Prevention, Assessment & Rehabilitation* 18 (1): 67–73.
- Skofter, B. 2007. "Low back pain in 15- to 16-year-old children in relation to school furniture and carrying of the school bag." *Spine* 32 (24): E713– E717.
- Smith-Zuzovsky, N., and C. Exner. 2004. "The effect of seated positioning quality on typical 6- and 7-year-old children's object manipulation skills." *American Journal of Occupational Therapy* 58 (4): 380–388.
- Straker, L., A. Briggs, and A. Greig. 2002. "The effect of individually adjusted workstations on upper quadrant posture and muscle activity in school children." *Work: A Journal of Prevention, Assessment & Rehabilitation* 18 (3): 239–248.
- Straker, L., C. Pollock, R. Burgess-Limerick, R. Skoss, and J. Coleman. 2008. "The impact of computer display height and desk design on muscle activity during information technology work by young adults." *Journal of Electromyography and Kinesiology* 18 (4): 606–617.
- Troussier, B., C. Tesniere, J. Fauconnier, J. Grisons, R. Juvin, and X. Phelip. 1999. "Comparative study of two different kinds of school furniture among children." *Ergonomics* 42 (3): 516-526.
- Tunay, M., and K. Melemez. 2008. "An analysis of biomechanical and anthropometric parameters on classroom furniture design." *African Journal of Biotechnology* 7 (8): 1081–1086.
- UNESCO Santiago, Ministerio de Educación de Chile. 2001. Guía de recomendaciones para el diseño del mobiliario escolar Chile [Recommendation Guide for Chilean School Furniture Design]. Santiago: UNESCO, MINEDUC

Van Niekerk, S., Q. A. Louw, K. Grimmer-Somers, J. Harvey, and K. J. Hendry. 2013. "The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school." *Applied Ergonomics* 44 (3): 366–371.

Wingrat, J. K., and C. E. Exner. 2005. "The impact of school furniture on fourth grade children ' s on-task and sitting behavior in the classroom: A pilot study." *Work: A Journal of Prevention, Assessment & Rehabilitation* 25 (3): 263–272.

Yeats, B. 1997. "Factors that may influence the postural health of schoolchildren (K-12)." *Work: A Journal of Prevention, Assessment & Rehabilitation* 9 (1): 45-55.

Zacharkow, D. 1987. *Posture: Sitting, Standing, Chair Design & Exercise*. Springfield: Charles C. Thomas.

CHAPTER 3| Equations for defining the mismatch between students and school furniture: a systematic review

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The present study reviews the scientific literature that describes the criteria equations for defining the mismatch between students and school furniture. This mismatch is likely to result in certain negative effects on students' performance and comfort. Fifteen studies were found to meet the criteria of this review and twenty-one equations to test six furniture dimensions were identified. It should be noted that a very high percentage of mismatch has been found in the use of chairs and tables. Some systematic errors have been found during the application of the different equations, such as the assumption that students are sitting on chairs with a proper seat height. Only one study considered the cumulative fit. Finally, there are some equations that are based on contradictory criteria and, as a result, there is a need to develop new equations for these cases, as well as a validation thereof. Ultimately, the present work is a contribution towards improving the evaluation of school furniture and could be used to design ergonomic-oriented classroom furniture.

Keywords: School; furniture; anthropometry; mismatch; equations.

3.1. Introduction

Students take part in one of the most sedentary occupations, the location of which is where permanent habits of sitting are formed (Lueder and Berg Rice, 2008; Zacharkow, 1987). Furthermore, poor sitting habits acquired during childhood are very difficult to change later in adolescence and/or adulthood (Yeats, 1997). Considering the above, it is fundamental that school furniture fulfill the children's requirements (Savanur et al., 2007). For example, it should allow for the changing of posture (Yeats, 1997) and as a result, students will benefit from using furniture that fits their body size (Wingrat and Exner, 2005).

A desirable improvement would be the use of adjustable school furniture that promotes a better posture when sitting and standing. In addition, there may be the added benefit of better overall academic performance (Koskelo et al., 2007).

However, most of the currently used school furniture has fixed dimensions and there are some standards that promote different sizes for a specific population (BSI, 2006; INN, 2002). This situation may be associated with the large number of studies published worldwide that show a clear mismatch between anthropometric characteristics and the dimensions of the furniture under study. For example: Castellucci et al. (2010), Chung and Wong (2007), Dianat et al. (2013), Gouvali and Boudolos (2006), Panagiotopoulou et al. (2004), Parcels et al. (1999) and Saarni et al. (2007).

This mismatch is likely to result in a number of negative effects. For example, learning can be affected since uncomfortable and awkward body postures can decrease a student's interest in learning, even during the most stimulating and interesting lessons (Hira, 1980). Murphy et al. (2007), concluded that chairs that are too low have a significant association with the occurrence of neck pain, upper back pain, and lower back pain. A chair's backrest that is too high has been significantly associated with lower back pain. While it is acknowledged that there is a multifactorial nature of causality of adolescent spinal symptoms, it is contended that the degree of mismatch between child anthropometry and school furniture set-up should be further examined as being a strong and plausible factor in the occurrence of adolescent lower back pain (Milanese and Grimmer, 2004).

However, Gouvali and Boudolos (2006) state that the equations used to examine the match or mismatch between school furniture and anthropometric dimensions can be problematic in the sense that they are sometimes based on contradictory criteria. Also, a series of mismatch equations were determined on the basis of either the prevailing or the more frequently stated viewpoints of other researchers.

Accordingly, the aim of this paper is to review the literature describing the criteria equations for defining the mismatch between students and school furniture. This is done by summarizing the level of mismatch found in the literature under review by discussing the various criteria equations and by proposing a methodology to evaluate school furniture suitability.

3.2. Methodology

The scientific publications database, SciVerse Scopus, was used to identify the studies carried out in the field of mismatch or the fit between child anthropometric measures and classroom furniture. The search terms used were "school furniture" and "classroom furniture".

The searches resulted in a total of 401 registries. The following criteria had to be fulfilled in order to be included in the current review: the articles had to be original studies, written in English and published between January 1980 and January 2013.

The review was oriented toward the definition of mismatch equations. Studies that merely presented a proposal of a new dimension set size for school furniture based on the application of percentiles were not considered.

Potential mismatch equations were grouped according to the specific type of school furniture under consideration:

- Chair dimensions;
- Table dimensions;
- Interaction between chair and table dimensions.

All mismatch equations, both one- and two-way, were considered. When the situation under analysis had a minimum and maximum limit, a two-way equation was considered appropriate and when it only had a maximum or a minimum limit, a one-way equation was the required option.

3.3. Results and Discussion

3.3.1. Generalities

Fifteen studies were found that met the criteria described above. The results from the studies included in the present review are shown in Table 3.1. The selected studies were undertaken in 11 different countries, covering Europe, Asia, Africa and America. All of the studies were cross-sectional and were published between 1999 and 2013.

The furniture and anthropometric dimensions were not all the same across the studies (Figures 3.1. and 3.2.). Regarding chair dimensions, Table 3.1. shows that all the studies considered needed to apply an equation to test the fit of the seat height (SH). This fact demonstrates that SH is the most important measure for the development of mismatch criterion. Furthermore, SH should be considered as the starting point and the most important variable for the design of classroom furniture (Molenbroek et al., 2003; Castellucci et al., 2010). Seat Depth (SD) was used in the majority of studies (14), being the second most common measurement. Only a few studies (5) applied a mismatch equation to test Seat Width (SW) and the Upper Edge of Backrest (UEB). Finally, on the topic of chair dimensions, none of the studies evaluated the Lower Edge of Backrest (LEBR), Width of Backrest (WBR), or Height of Backrest (HBR).

Table 3.1. Resume of studies

Author and year	Sample	Location	Chair			Table		Chair and Table		
			SH	SD	SW	UEB	DH	UDH	SDH	SDC
Afzan et al., 2012	91 students from 2 nd and 5 th grade, between 8 and 11 years old.	Malaysia	X	X	X	X	X			
Agha, 2010	600 students from the 1 st to 6 th grade, between 6 and 11 years old.	Palestine	X	X		X	X	X		
Batistão et al., 2010	48 students from the 5 th and 8 th grade.	São Carlos, São Paulo, Brasil	X	X					X	
Brewer et al., 2009	137 students from 5 th To 12 th grade.	Ohio State, United States	X	X				X	X	
Castellucci et al., 2010	195 students from 8 th grade, between 12,5-14,5 years old.	Valparaiso Region, Chile	X	X	X	X			X	X
Chung and Wong, 2007	214 students from 5 th and 6 th grade, between 10 and 13 years old.	Hong Kong, China	X	X			X	X		
Cotton et al., 2002	211 students from 6 th to 8 th grade, between 10-13 years old.	Texas, United States	X	X			X	X		
Dianat et al., 2013	978 students from 9 th to 12 th grade, between 15 and 18 years old.	Iran	X	X	X	X			X	
Gouvali and Boudolos, 2006	274 students from 1 st to 12 th grade, between 6 and 18 years old.	Athens, Greece	X	X	X	X	X	X		
Jayaratne and Fernando, 2009	1607 students from 6 th to 8 th grade, between 11 and 13 years old.	District of Gampaha, Sri Lanka	X	X				X		
Jayaratne, 2012	1607 students from 6 th to 8 th grade, between 11 and 13 years old.	District of Gampaha, Sri Lanka	X	X				X		
Panagiotopoulou et al., 2004	180 students from 2 nd , 4 th and 6 th , between 7 and 12 years old.	Thessaloniki, Greece	X	X			X	X		
Parcells et al., 1999	74 students from 6 th to 8 th grade, between 11 and 13 years old.	Michigan, United States	X	X			X	X		
Ramadan, 2011	124 students from 1 st to 6 th grade, between 6 and 13 years old.	Saudi Arabia	X				X			
Van Niekerk, 2013	689 students 8 th to 12 th grade, between 13 and 18 years old.	Western Cape, South Africa	X	X	X					

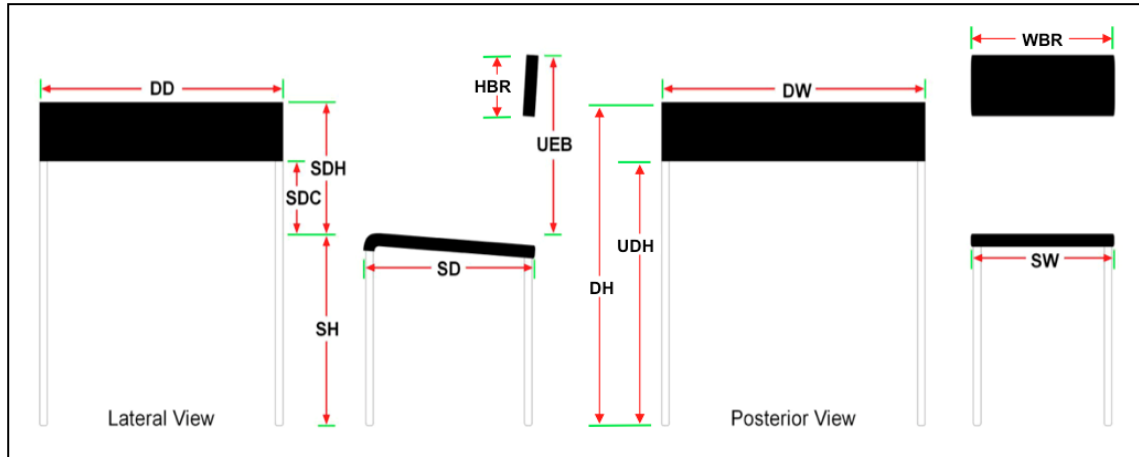


Figure 3.1. Representation of classroom furniture dimensions: Seat Height (SH), Seat Depth (SD), Seat Width (SW), Upper Edge of Backrest (UEB), Lower Edge of Backrest (LEBR), Width of Backrest (WBR), Height of Backrest (HBR), Desk Width (DW), Desk Depth (DD), Desk Height (DH), Underneath Desk Height (UDH), Seat to Desk Clearance (SDC) and Seat to Desk Height (SDH).

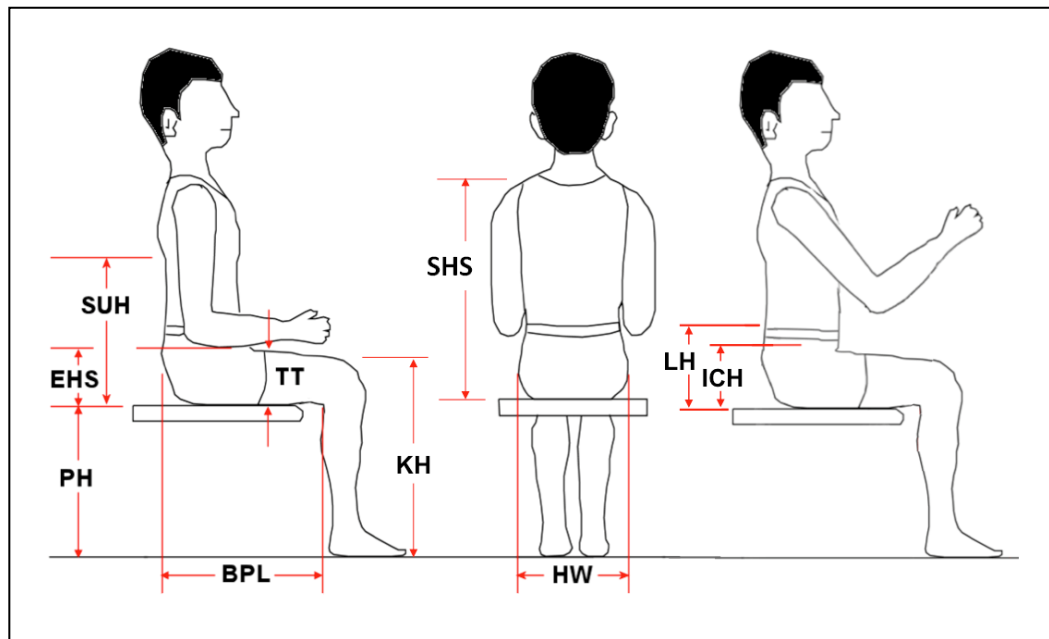


Figure 3.2. Representation of the anthropometric measurements: Popliteal Height (PH), Buttock Popliteal Length (BPL), Hip Width (HW), Subscapular Height (SUH), Shoulder Height (SHS), Iliac Crest Height (ICH), Lumbar Height (LH), Thigh Thickness (TT), Knee Height (KH) and Elbow Height Sitting (EHS)

Concerning table dimensions, it is important to mention that there are two dimensions, namely Desk Width (DW) and Desk Depth (DD), for which no mismatch equations were found. Castellucci et al. (2010), defined these dimensions according to functional criteria, such as the need for available desk surface to perform school activities, for instance reading and writing. On the other hand, Desk Height (DH) and Underneath Desk Height (UDH) were evaluated in eight and nine studies, respectively.

The interaction between chair and table dimensions is measured by Seat to Desk Clearance (SDC), which results from the difference between UDH and SH, and was only used once. This mismatch equation tests the same furniture dimension as UDH, but in this paper, it is shown that a number of authors have not correctly applied the equation. Furthermore, the same can be said of Seat to Desk Height (SDH) dimensions, which were used four times and result from the difference between DH and SH.

Finally, Table 3.2. shows a summary of relationships between anthropometric measures and school furniture dimensions.

Table 3.2. Summary of relationship between anthropometric measurements and school furniture dimensions

School furniture dimension	Anthropometric measurement
Seat Height (SH)	Popliteal Height (PH)
Seat Depth (SD)	Bottom Popliteal Length (BPL)
Seat Width (SW)	Hip Width (HW)
Upper Edge of Backrest (UEB)	Subscapular Height (SUH)
	Shoulder Height Sitting (SHS)
Lower Edge of Backrest (LEBR)	Iliac Crest Height (ICH)
	Lumbar Height (LH)
Width of Backrest (WBR)*	Not used among the reviewed studies
Height of Backrest (HBR)	Lumbar Height (LH)
	Subscapular Height (SUH)
Desk Width (DW)	Functional criteria
Desk Depth (DD)	Functional criteria
	Knee Height (KH)
Underneath Desk Height (UDH)	Popliteal Height (PH)
	Elbow Height Sitting (EHS)
	Shoulder Height Sitting (SHS)
Seat to Desk Clearance (SDC)	Thigh thickness (TT)
	Popliteal Height (PH)
Desk Height (DH)	Elbow Height Sitting (EHS)
	Shoulder Height Sitting (SHS)
Seat to Desk Height (SDH)	Elbow Height Sitting (EHS)

* WBR was not used among the studies under review, despite Garcia-Acosta and Lange-Morales (2007) proposition to the use of the distance between elbows.

3.3.2. Criteria equations for mismatch of chair dimensions

3.3.2.1. Seat Height

Most of the researchers have concluded that Popliteal Height (PH) should be higher than SH (Mokdad and Al-Ansari, 2009; Molenbroek and Ramaekers, 1996; Parcels et al., 1999), otherwise most students will be unable to rest their feet on the floor properly, thus generating increased tissue pressure on the posterior surface of the knee (García-Molina et al., 1992; UNESCO, 2001; Milanese and Grimmer, 2004). However, if SH is significantly lower than PH, this increases the compression in the buttock region (García-Molina et al., 1992), while also increasing the degree of lumbar flexion involved in sitting (Pheasant, 2003). This leads to two of the main

equations to be found in the literature. One is based on the angles of the knee (Eq.1), considering that SH needs to be lower than PH so that the lower leg forms a 5-30° angle relative to the vertical. The other equation includes two options (Eq. 2 and 3), but both are based on the fact that SH has to be evaluated in relation to the PH percentage.

One can find the following equations in the literature, where SC is shoe correction:

$$(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ \quad (\text{Eq. 1})$$

$$0.88PH \leq SH \leq 0.95PH \quad (\text{Eq. 2})$$

$$0.80PH \leq SH \leq 0.99PH \quad (\text{Eq. 3})$$

In the three different equations, two-way mismatch criterion is considered. In all the studies that were analyzed, the anthropometric measurements were made without shoes. Only one equation (Eq. 1) considers the use of shoe correction with a height between 2cm (Agha, 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006) and 3cm (Castellucci et al., 2010). It is also necessary to consider that SC may naturally vary according to culture, fashion, and country. For example, other authors also recommend shoe corrections with values between 2.5cm (Herzberg, 1972) and 4.5cm (Pheasant, 1984). The discrepancies regarding the use of SC may affect the overall results in the different studies that applied Equations 2 and 3 (Table 3.3.). It seems most likely that the lowest degree of mismatch will appear if shoe correction is applied. This situation appears to affect the results of ten studies where Equation 2, the most popular equation, was applied (Table 3.1.). Moreover, Equation 3 was mentioned several times in the studies but only one study offered actual results. This may be because this equation embodies a less strict definition of mismatch.

Some differences in the results can be explained by applying the three different equations for mismatch SH. As an example, a student with a PH of 38cm will fit on a chair with SH from 35.5cm to 40.8cm (including a shoe correction of 3cm), from 33.4cm to 36.1cm, and from 30.4cm to 37.7cm when applying Equations 1, 2 and, 3, respectively. The results show considerable differences between the two most frequently used equations: the lowest limit from Eq.1 is almost equal to the highest limit of Eq. 2. This discrepancy can be reduced by applying the same shoe correction to Equations 2 and 3. The results would then be 36cm and 39cm for Eq.2 and 32.8cm and 40.5cm for Eq. 3. As expected, the difference between the limits of the equations has decreased. Despite this, the range between the low and high limit differs between the three equations, where Eq.3 is the least strict and Eq.2 is the most strict.

Despite the use of two-way equations, in Table 3.3, half of the studies present the overall mismatch and do not differentiate between low and high mismatch. With regard to the overall results, most of the situations in the different studies present high levels of mismatch. Furthermore, when the two levels of mismatch are considered,

it is possible to conclude that most of the students were provided with a higher chair than they actually needed. On the other hand, only the study of Batistão et al. (2010), presented a situation with 50% of low mismatch.

3.3.2.2. *Seat Depth*

Buttock Popliteal Length (BPL) is the anthropometric measure used to designate the size of the Seat Depth (SD) (Helander, 1997; Khalil et al., 1993; Occhipinti et al., 1993; Orborne 1996). If SD is greater than BPL, the student will not be able to use the backrest of the seat to support the lumbar spine without compression of the popliteal surface (Milanese and Grimmer, 2004). To avoid this, the student will generally move their buttocks forward toward the edge of the seat (Panagiotopoulou et al., 2004). This improper usage of the backrest causes kyphotic posture (Khalil et al., 1993; Pheasant, 1991). On the other hand, if the SD is considerably shorter than the BPL of the student, then the thigh will not be fully supported. The studies included in this review present two equations that use the principle of percentage, but differ in the amount considered. The two equations are:

$$0.80BPL \leq SD \leq 0.95BPL \quad (\text{Eq. 4})$$

$$0.80BPL \leq SD \leq 0.99BPL \quad (\text{Eq. 5})$$

Equation 4 uses a stricter definition of mismatch and it is the most frequently used equation (Table 3.3.). The difference between the two equations is 4% of BPL, which will affect the high limit of SD. The lower limit remains the same for the two equations, at 80% of BPL. Despite the use of the two-way equation, six studies present the results of the overall mismatch without presenting high or low mismatch. These results show high levels of mismatch ranging from 70% to 99.8% of mismatch. Regarding the levels of mismatch, it can be concluded that there is a higher percentage of low mismatch than high mismatch, due to a SD that is too shallow. This situation will generate discomfort as the thigh is not entirely supported.

Table 3.3. Resume Criteria Equation for mismatch of chair dimensions

Dimension	Equation	Author and year	Level of mismatch
SH	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$	Afzan et al., 2012	Low: 2 nd grade, 0% and 5 th grade, 79%; High: 2 nd grade, 100% and 5 th grade, 0%.
		Agha, 2010	99,8 %
		Castellucci et al., 2010	Low: School A, 0%; School B, 0% and School C, 1%; High: School A, 86%; School B, 72% and School C, 88%
		Dianat et al., 2013	Low: Boys, 1.5% and Girls 4.4%; High: Boys 65.8% and Girls 50.1%
	Eq. 2: $0.88PH \leq SH \leq 0.95PH$	Gouvali and Boudolos, 2006	Low: situation 1, 1.1% and situation 2, 1.1%; High: situation 1, 71.5% and situation 2, 21.5%
		Batistão et al., 2010	Low: 5 th grade, 23% and 8 th grade, 50%; High: 5 th grade, 41% and 8 th grade 0%
		Brewer et al., 2009	Low: 5 th –6 th grade, 7.7%; 7 th –8 th grade, 2%; 9 th –10 th grade, 10.6% and 11 th –12 th grade, 9.7%; High: 5 th –6 th grade, 43.2%; 7 th –8 th grade, 61.5%; 9 th –10 th grade, 13.2% and 11 th –12 th grade, 14.9%
		Chung and Wong, 2007	Low: Large chair, 0% and Small chair 0%; High: Large chair, 100% and Small chair, 94%
		Cotton et al., 2002	Chair 1, 64%; Chair 2, 58.3% and Chair 3, 61.6%
		Jayaratne and Fernando, 2009	79.8%
		Jayaratne, 2012	79.8%
		Panagiotopoulou et al., 2004	2 nd grade 95% (old and new furniture 1 st to 3 rd grade); 4 th grade 46.7% (old and new furniture 1 st to 3 rd grade) and 100% (old and new furniture 4 th to 6 th grade); 6 th grade 66.7% (new furniture 4 th to 6 th grade) and 100% (old and high school furniture)
		Parcells et al., 1999	Low: Chair 1, 1.4%; Chair 2, 0% and Chair 3, 0%; High: Chair 1, 81.1%; Chair 2, 81.2% and Chair 3, 90.6%
		Ramadan, 2011	High chair 92.8%; 1stMid chair 69.3%; 2ndMid chair 6.5% and Low chair 7.3%.
		Van Niekerk et al., 2013	Chair 1, 65% and Chair 2, 75%.
	Eq. 3: $0.80PH \leq SH \leq 0.99PH$	Ramadan, 2011	This was the formula considered to be the critical fit. The results are the same as presented above.

Table 3.3. Resume Criteria Equation for mismatch of chair dimensions (Continued)

Dimension	Equation	Author and year	Level of mismatch
SD	Eq. 4: $0.80BPL \leq SD \leq 0.95BPL$	Afzan et al., 2012	Low: 2 nd grade, 0% and 5 th grade, 100%; High: 2 nd grade, 100% and 5 th grade, 0%.
		Agha, 2010	99.8%
		Batistão et al., 2010	Low: 5 th grade, 5% and 8 th grade, 86%; High: 5 th grade, 19% and 8 th grade, 0%
		Brewer et al., 2009	Low: 5 th –6 th grade, 37.2%; 7 th –8 th grade, 79.7%; 9 th –10 th grade, 89.6% and 11 th –12 th grade, 94.2%; High: 5 th –6 th grade, 20.5%; 7 th –8 th grade, 3.1%; 9 th –10 th grade, 2.1% and 11 th –12 th grade, 0.2%
		Castellucci et al., 2010	Low: School A, 25%; School B, 24% and School C, 39%; High: School A, 5%; School B, 0% and School C, 0%
		Chung and Wong, 2007	Low: Large chair, 6.5% and Small chair 19.2%; High: Large chair, 13.1% and Small chair, 6.5%
		Cotton et al., 2002	99%
		Dianat et al., 2013	Low: Boys, 3.5% and Girls 3.2%; High: Boys 22.6% and Girls 22.5%
		Jayarathne and Fernando, 2009	87,3%
		Jayarathne, 2012	87,3%
SW	Eq. 5: $0.80BPL \leq SD \leq 0.99BPL$	Panagiotopoulou et al., 2004	2 nd grade 100% (old and new furniture 1 st to 3 rd grade); 4 th grade 70% (new and old furniture 4 th to 6 th grade); 6 th grade high mismatch 23.3% and low mismatch 5% (new and old furniture 4 th to 6 th grade)
		Parcells et al., 1999	Low: Chair 1, 0%; Chair 2, 1.4% and Chair 3, 16.2%; High: Chair 1, 70.3%; Chair 2, 23% and Chair 3, 14.9%
		Van Niekerk et al., 2013	Chair 1, 76% and Chair 2, 84%.
		Gouvali and Boudolos, 2006	Low: situation 1, 48.9% and situation 2, 44.9%; High: situation 1, 12.4% and situation 2, 12%
		Afzan et al., 2012	No results
		Castellucci et al., 2010	School A, 8%; School B, 10% and School C, 10%
UEB	Eq. 6: $HW < SW$	Dianat et al., 2013	Low: Boys, 29.7% and Girls 72.9%; High: Boys 6% and Girls 0.8%
		Gouvali and Boudolos, 2006	Low: situation 1, 9.5% and situation 2, 7.7%; High: situation 1, 33.2% and situation 2, 30.3%
		Van Niekerk et al., 2013	Chair 1, 65% and Chair 2, 71%.
		Afzan et al., 2012	Low: 2 nd grade, 44% and 5 th grade, 91%; High: 2 nd grade, 0% and 5 th grade, 7%.
UEB	Eq. 7: $1.1HW \leq SW \leq 1.3HW$	Agha, 2010	35%
		Dianat et al., 2013	Low: Boys, 0% and Girls 0%; High: Boys 14% and Girls 14.3%
		Gouvali and Boudolos, 2006	Low: situation 1, 2.6% and situation 2, 2.9%; High: situation 1, 19.7% and situation 2, 13.1%
		Castellucci et al., 2010	School A, 8%, School B, 50% and School C, 7%

3.3.2.3. Seat Width

To be able to relieve the pressure on the buttocks and to avoid discomfort and mobility restrictions, Seat Width (SW) should be higher than Hip Width (HW) (Evans et al., 1988; Helander, 1997; Occhipinti et al., 1993; Orborne, 1996; Oyewole et al., 2010; Sanders and McCormick, 1993). Moreover, Gouvali and Boudolos (2006) suggested that SW should be at least 10%, but not more than 30%, larger than HW in order to provide proper seating while making economic use of space. In this case, the corresponding mismatch equations are:

$$HW < SW \quad (\text{Eq. 6})$$

$$1.1HW \leq SW \leq 1.3HW \quad (\text{Eq. 7})$$

SW presents one-way and two-way equations. Both equations take low limit or low mismatch into account. However, only Equation 7 presents a margin of 10%, which generates a more strict equation. It is important to note that this margin is more important for office chairs than for school chairs due to the more frequent use of an arm support. As can be seen in Table 3.3, only the study by Dianat et al. (2013), presents high levels of low mismatch causing discomfort in the buttock area. On the other hand, if there is a low level of high mismatch, this can be considered to be of secondary importance due to the fact that it affects economy of space rather than the student's seating posture. Van Niekerk et al. (2013), also applied Equation 7 and discovered high levels of mismatch. However, it is not possible to determine if this mismatch is high or low.

3.3.2.4. Upper edge of Backrest

When students use a chair with UEB higher than Subscapular Height (SUH), this will result in compression of the scapula and a reduction in arm and trunk mobility (Garcia-Acosta and Lange-Morales, 2007; Orborne 1996). As a result, the equations are:

$$0.6SHS \leq UEB \leq 0.8SHS \quad (\text{Eq. 8})$$

$$SUH \geq UEB \quad (\text{Eq. 9})$$

Only two equations were found for calculating these dimensions and only Equation 8 was based on two-way limits. This equation was first used in the studies under review by Gouvali and Boudolos in 2006 and is based on the percentage of SHS. However, none of the studies explain why they used 60% and 80% of SHS, respectively. On the other hand, Equation 9 is based on a one-way limit by verifying and assuming that if SUH is higher than UEB, the arm and scapula will be able to move freely. The results, in Table 3.3, show low levels of mismatch. Please note that it is not possible to make a direct comparison between the results of the applied equations since the school furniture and anthropometrics measure originate from different studies.

Finally, none of the studies include mismatch equations for LEBR, WBR, and HBR, most likely because they were considered to be of secondary importance. In addition, the anthropometrics dimensions Iliac Crest Height (ICH) and Lumbar Height (LH) used in comparison with LEBR and HBR (Garcia-Acosta and Lange-Morales, 2007; Molenbroek et al., 2003) are difficult to measure. Furthermore, another anthropometric measurement is needed in order to get the HBR ($HBR = SUH - LH$).

3.3.3. Criteria equation for mismatch of table dimensions

As explained earlier and to avoid any misunderstanding, it should be highlighted that Desk Height (DH) and Underneath Desk Height (UDH) will be analysed with Seat to Desk Height (SDH) and Seat to Desk Clearance (SDC), respectively (Table 3.4.).

3.3.4. Criteria equation for mismatch of chair and table dimensions

3.3.4.1. Seat to Desk Clearance

SDC has to be large enough in order to allow the students to push the chair under the table and to have enough space to allow leg movement. Accordingly, SDC is considered appropriate when it is higher than Thigh Thickness (TT) (Eq. 12) (Garcia-Acosta and Lange-Morales, 2007; Molenbroek et al., 2003). Parcels et al. (1999), proposed that the desk clearance should be 2cm higher than Knee Height (KH) (Eq. 11). Gouvali and Boudolos (2006), considered a high limit regarding the maximum DH and the table thickness (Eq.13). The five equations considered for these dimensions are as follows:

$$KH + SC + 2 < UDH \quad (\text{Eq. 10})$$

$$KH + 2 < UDH \quad (\text{Eq. 11})$$

$$TT + 2 < SDC \quad (\text{Eq. 12})$$

$$(KH + SC) + 2 \leq UDH \leq [(PH + SC) \cos 5^\circ] + (EHS * 0.8517) + (SH * 0.1483) - 4 \quad (\text{Eq. 13})$$

$$PH + 20 < UDH \quad (\text{Eq. 14})$$

These dimensions reveal a great diversity of approach and, consequently, of equations. Furthermore, there is also considerable variability in the anthropometric measures used to define the level of furniture match.

To analyse this situation, it is important to remember that the papers' authors were looking to compare the "actual" classroom furniture dimensions and the anthropometrics were gathered in an erect position, with subjects' upper and lower legs at a 90° angle and with their feet flat on the floor or on an adjustable footrest. This means that KH can be the highest point of the lower limbs, but, as mentioned earlier, most of the students were using a high seat; therefore, KH will be lower than SH + TT. Those studies that used Equation 10 and 11

presented low levels of mismatch, which are likely to be underestimated (Table 3.4.). Additionally, the non-consideration of shoe correction is another error in the equation that can affect results.

Equation 13 allows for shoe correction, but still maintains the incorrect assumption that students are sitting in a chair with proper SH. Furthermore, this raises the very interesting point that the high limit used tries to solve one of the major problems regarding two main school furniture dimensions – UDH and DH. This high limit assumes that UDH cannot be higher than the maximum DH minus table thickness. This problem will be discussed at the end of the following section.

Equation 14 paints an unclear picture when one takes into consideration that 20cm is (proportionally) a very different amount for students that are 6 years old and students that are 17 years old, including all ages in between. Finally, Equation 12 is the only one that uses TT, as it compares this anthropometric measure to SDC. One possible variant to this equation could be $SH + TT + 2$ against UDH.

UDH results are shown in Table 3.4. Very low levels of mismatch were found in the majority of studies, except for the results of the studies in which Equation 14 was applied (Jayaratne and Fernando, 2009; Jayaratne, 2012).

3.3.4.2. Seat to Desk Height

If SDH or DH is too low, students are forced to bend their torso forward, with their body weight supported by the arms. This will result in a kyphotic spinal posture with round shoulders. Conversely, a SDH or DH that is too high will cause the students to flex and abduct their upper arms as well as raise their shoulders. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture (Zacharkow, 1988).

Elbow Height Sitting (EHS) is the major criterion for SDH (Garcia-Acosta and Lange-Morales, 2007; Milanese and Grimmer, 2004; Molenbroek et al., 2003; Sanders and McCormick, 1993). It is also accepted that EHS can be considered as the minimum height of SDH, in order to provide a significant reduction on spinal loading (Occhipinti et al., 1985). In the case of the maximum SDH, Chaffin and Anderson's principles (1991) depend on shoulder flexion and shoulder abduction angles of 25° and 20°, respectively. Other researchers recommended that the desk should not be higher than 5cm above EHS. It is important to mention that some of these equations are not set out as they were presented in the original paper, but rather as they were applied. The following equations allow the computation of the mismatch level:

$$EHS + [(PH+CS) \cos 30^\circ] \leq DH \leq [(PH+CS) \cos 5^\circ] + EHS * 0.8517 + SHS * 0.1483 \quad (\text{Eq. 15})$$

$$EHS \leq SDH \leq EHS * 0.8517 + SHS * 0.1483 \quad (\text{Eq. 16})$$

$$EHS \leq SDH \leq EHS + 5 \quad (\text{Eq. 17})$$

$$(SH + EHS * 0.8517 + SHS * 0.1483) - DH < 0, \text{ desk is too high} \quad (\text{Eq. 18})$$

$$\{(EHS * 0.8517 + SHS * 0.1483) + [SH - (\sin 5^\circ SD)]\} - DH < 0, \text{ desk is too high} \quad (\text{Eq. 19})$$

$$SH+EHS \leq DH \leq SH + EHS*0.8517+ SH*0.1483 \quad (\text{Eq. 20})$$

$$[SH - (\sin 5^\circ SD)] + EHS \leq DH \leq [SH - (\sin 5^\circ SD)] + EHS*0.8517+ SHS*0.1483 \quad (\text{Eq. 21})$$

SDH is the furniture dimension with the greatest number of equations in the literature. However, most of these, with the exception of Equation 17, were based on Chaffin and Anderson's principles (1991) and were used for the first time in the context of school furniture by Parcels et al. (1999). Notwithstanding this, all equations took the EHS as being the lowest limit of SDH.

In Equation 15, as previously mentioned, when analysing SDC equations, the authors worked with the incorrect assumption that students were sitting in a chair with a proper SH.

Equations 16, 20, and 21 are quite similar, but they differ in certain respects. The latter two equations include the seat height, while Equation 16 tests SDH. Also, the backward slope of the chairs is considered in Equation 21, since the elbow is aligned with the back of the seat and is lower than the front edge. This height can be easily calculated as, for example, in the case of a seat with 5° of backward slope or negative seat angle, it would be: $SH - SD * \sin X^\circ$.

Equations 18 and 19 only take the high limit or high mismatch into consideration and therefore, could be considered to be one-way equations. This might be a mistake, in the author's opinion, since a low mismatch in this equation may originate from problems related to a low desk. Additionally, Equation 19 takes the backward slope into consideration.

Finally, Equation 17 is established to test the high limit and a flat 5cm is added to every EHS. Again, this may lead to some problems since the angles of abduction and flexion of the shoulder joint will not be the same for students with different EHS and SHS.

A number of the studies that focused on this furniture dimension (Table 3.4.) report the highest levels of overall mismatch. A very high level of high mismatch was also reported and in several studies the value of the mismatch reached 100%.

As previously mentioned, the criteria applied to test the fit of SDH and SDC can sometimes be contradictory. This may occur when there is:

- A small difference between the anthropometric dimensions TT and EHS. This can be influenced by the stage of growth, anthropometric characteristics, food intake, and other characteristics of the student.
- Interrelation between certain factors. For example, the 2cm used for free space in Equation 12, refers to the table thickness influenced by the materials used for the structure and the presence of a drawer. In some standards, the minimum considered for the structure is 7cm (INN, 2002) and in others it is

7.5cm (BSI, 2006). Another example is the way that the principles used to define the maximum EHS are applied.

- To explain this situation more clearly, one could take the example of a student who has a SDC match:

$$\text{Exact SDC match} = \text{Maximum SDH}$$

$TT + 2$ (free space) + 7 (table thickness) = EHS + 5, meaning that a SDH match is obtained if the student has, at least, an EHS 4cm higher than TT.

There are not many changes that can be made to the SDC equation since it is a convenient equation for the determination of space and can be easily applied if the researchers use TT instead of KH. On the other hand, there is not sufficient data available either to justify changing the SDH equations or to continue using those presented in this review. The criteria presented by Chaffin and Anderson (1991) do not take elbow or forearm support into consideration, which could reduce the strain on the shoulder (Feng et al., 1997; Slot et al., 2009). Furthermore, there are some authors who suggest that for writing and drawing with forearm or elbow support, the table should be positioned at 10cm above EHS (Pheasant, 2003; Kroemer and Grandjean, 1997).

Finally, it should also be emphasized that it is important to consider the cumulative fit or transversal mismatch, which is defined as the mismatch that takes the cumulative values of the different furniture dimensions into account. This can be considered as a very important indicator of furniture fit, since it shows how many students are actually matched to the dimensions of their school furniture. Most of the studies that were analysed in the current review did not consider this overall perspective, but instead showed isolated results for each dimension of the furniture. One exception is the work performed by Batista et al. (2010). They remarked that when the furniture was seen as a conjunction of several measurements, the results showed that only one student (from their sample) had an adequate seat and table. There are also other studies that use cumulative fit for chair dimensions, namely SH and SD (Brewer et al., 2009; Cotton et al., 2002; Parcells et al., 1999).

Table 3.4. Resume Criteria Equation for mismatch of interaction between chair and table dimensions

Dimension	Equation	Author and year	Level of mismatch
SDC or UDH	Eq. 10: $KH + SC + 2 < UDH$	Agha, 2010	9%
	Eq. 11: $KH + 2 < UDH$	Brewer et al., 2009	5 th –6 th grade, 25%; 7 th –8 th grade, 37.5%; 9 th –10 th grade, 47.4% and 11 th –12 th grade, 52.4%
		Chung and Wong, 2007	No results
		Cotton et al., 2002	0%
		Panagiotopoulou et al., 2004	2 nd grade 0% (old and new furniture 1 st to 3 rd grade); 4 th grade 0% (old furniture 4 th to 6 th grade) and 1.7% (new furniture 4 th to 6 th grade); 6 th grade 1.7% (old furniture 4 th to 6 th grade) and 26.7% (new furniture 4 th to 6 th grade)
		Parcells et al., 1999	Chair 1, 0%; Chair 2, 0% and Chair 3, 0%
	Eq. 12: $TT + 2 < SDC$	Castellucci et al., 2010	School A, 11%; School B, 10% and School C, 36%
	Eq. 13: $(KH + SC) + 2 \leq UDH \leq [(PH+SC) \cos 5^\circ] + (EHS*0.8517) + (SHS*0.1483) - 4$	Gouvali and Boudolos, 2006	Low: situation 1, 5.8% and situation 2, 5.1%; High: situation 1, 15.3% and situation 2, 5.1%
	Eq. 14: $PH + 20 < UDH$	Jayaratne and Fernando, 2009	76.3%
		Jayaratne, 2012	76.3%

Table 3.4. Resume Criteria Equation for mismatch of interaction between chair and table dimensions (Continued)

Dimension	Equation	Author and year	Level of mismatch
DH or SDH	Eq. 15: $EHS + [(PH+CS) \cos 30^\circ] \leq DH \leq [(PH+CS) \cos 5^\circ] + EHS \cdot 0.8517 + SHS \cdot 0.1483$	Afzan et al., 2012	Low: 2 nd grade, 0% and 5 th grade, 100%; High: 2 nd grade, 100% and 5 th grade, 0%.
		Agha, 2010	99.8%
		Gouvali and Boudolos, 2006	Low: situation 1, 0.4% and situation 2, 0.4%; High: situation 1, 81.8% and situation 2, 33.9%
	Eq. 16: $EHS \leq SDH \leq EHS \cdot 0.8517 + SHS \cdot 0.1483$	Batistão et al., 2010	Low: 5 th grade, 18% and 8 th grade, 38%; High: 5 th grade, 73% and 8 th grade, 33%
		Brewer et al., 2009	Low: 5 th –6 th grade, 0.8%; 7 th –8 th grade, 0%; 9 th –10 th grade, 1.5% and 11 th –12 th grade, 7.7%; High: 5 th –6 th grade, 94.3%; 7 th –8 th grade, 100%; 9 th –10 th grade, 67.4% and 11 th –12 th grade, 55.8%
	Eq. 17: $EHS \leq SDH \leq EHS + 5$	Castellucci et al., 2010	Low: School A, 0%; School B, 0% and School C, 0%; High: School A, 100%; School B, 100% and School C, 99%
		Dianat et al., 2013	Low: Boys, 40.8% and Girls 41.6%; High: Boys 9.7% and Girls 11.4%
	Eq. 18: $(SH + EHS \cdot 0.8517 + SHS \cdot 0.1483) - DH < 0$, desk is too high	Chung and Wong, 2007	Girls, 51.4% (Large chair) and 98.1% (Small chair); Boys, 71.1% (Large chair) and 100% (Small chair)
	Eq. 19: $((EHS \cdot 0.8517 + SHS \cdot 0.1483) + [SH - (\sin 5^\circ SD)]) - DH < 0$, desk is too high	Cotton et al., 2002	99%
	Eq. 20: $SH + EHS \leq DH \leq SH + EHS \cdot 0.8517 + SH \cdot 0.1483$	Panagiotopoulou et al., 2004	2 nd grade 88.3% (new furniture 1 st to 3 rd grade) and 96.7% (old furniture 1 st to 3 rd grade); 4 th grade 100% (old furniture 4 th to 6 th grade), 93.3% (new furniture 4 th to 6 th grade) and 70% (new furniture 1 st to 3 rd grade); 6 th grade 73.3% (new furniture 4 th to 6 th grade), 93.3% (old furniture 4 th to 6 th grade) and 96.7% (high school furniture)
		Ramadan, 2011.	High desk 100%; 1stMid desk 88,7%; 2ndMid desk 7,3% and Low desk 9,7%.
	Eq. 21: $[SH - (\sin 5^\circ SD)] + EHS \leq DH \leq [SH - (\sin 5^\circ SD)] + EHS \cdot 0.8517 + SHS \cdot 0.1483$	Parcells et al., 1999	Low: Desk 1 with: Chair 1, 0%; Chair 2, 0%; Chair 3, 0% and Desk 2 with: Chair 1, 0%; Chair 2, 0%; Chair 3, 0% High: Desk 1 with: Chair 1, 98.7%; Chair 2, 98.7%; Chair 3, 98.9% and Desk 2 with: Chair 1, 97.3%; Chair 2, 95.9%; Chair 3, 93.2%

3.3.5. Methodology of evaluation of school furniture suitability

This methodology is based on the mismatch equations that have been found and it is important to remember, as discussed earlier, that some of these are based on contradictory criteria.

When testing the level of mismatch between school furniture and anthropometric measures, the analysis should begin from the bottom to the top, known as the bottom-top approach. This requirement stems from the fact that SH is the most important measure for mismatch criteria.

There are some main furniture dimensions that need to be considered within this type of research, specifically those that are frequently used in the reviewed studies (Table 3.5.).

Finally, it is important to consider the cumulative fit or transversal mismatch using the bottom-top approach. For example, the testing has the following order: SH, SD, SW, UEB, SDC, and DH.

Table 3.5. Resume Criteria Equation to evaluate school furniture suitability

School Furniture Dimension	(mis)match equation	Observation
SH*	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$	
SD*	Eq. 4: $0.80BPL \leq SD \leq 0.95BPL$	
SW	Eq. 6: $HW < SW$	
UEB	Eq. 9: $SUH \geq UEB$	
SDC*	Eq. 12: $TT + 2 < SDC$	If SDC was not gathered, UDH can be used with the following formula: $SH + TT + 2 < UDH$. If the researchers have only gathered KH, TT can be estimated with the following equation: $(KH - PH) * 1.7$, this equation was developed by the authors using the average and standard deviations of PH, TT, and KH from different databases (Musa, 2011; Pheasant, 2003; Savanur et al., 2007)
DH*	Eq. 21: $(SH - (\sin X^\circ SD)) + EHS \leq DH \leq (SH - (\sin X^\circ SD)) + EHS * 0.8517 + SHS * 0.1483$	This equation is with X° backward slope or negative seat angle. If the seat has forward slope or positive angle it should be: $SH + SD * \sin 5^\circ$.

* Main furniture dimensions

3.4. Conclusion

This paper describes an approach for systematically listing the equations used for determining the level of mismatch found in anthropometric studies involving school furniture. The results that have been obtained indicate a high number of applied equations, considering various aspects of the mismatch estimation. The results in the reviewed studies that are presented here highlight the high percentage of mismatch found in the use of chairs and tables, i.e., most students use a higher chair and table than they actually need.

Some systematic errors have been found during the application of the equations, such as the non-consideration of shoe correction and the assumption that students are sitting on a chair with a proper seat height. These factors have a significant effect on the reported level of mismatch presented in the studies under review.

Almost all the studies have defined the mismatch levels individually, i.e., by defining criteria equations for each measurement separately. This means that the estimation of the mismatch is not achieved by considering the cumulative of values of the different furniture dimensions. This appears to lead to an underestimation of the levels of mismatch.

It is important to emphasize that the mismatch values presented by each study are not directly comparable, since the level of mismatch is not only affected by the equation used, but also by the anthropometric data considered, i.e., by the specific sample being considered. Accordingly, it would appear that the next study will be the comparison of the mismatch values for the different equations by using the sample of students gathered in Valparaíso Region, Chile during 2012.

Finally, it should also be acknowledged that there are a number of equations that are based on contradictory criteria and that it will be necessary to develop and validate new equations for these instances.

References

- Afzan, Z., Hadi, S., Shamsul, B., Zailina, H., Nada, I., Rahmah, A., 2012. Mismatch between school furniture and anthropometric measures among primary school children in Mersing, Johor, Malaysia. Network of Ergonomics Societies Conference (SEANES), Southeast Asia.
- Agha, S. R., 2010. School furniture match to students' anthropometry in the Gaza Strip. *Ergonomics* 53 (5): 344–354.
- Batistão, M. V., Sentanin, A. C., Moriguchi, C. S., Hansson, G., Coury, H. J. C., Sato, T., 2012. Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs. *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1): 4817-4824.
- Brewer, J. M., Davis, K. G., Dunning, K. K., Succop, P. A., 2009. Does ergonomic mismatch at school impact pain in school children? *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4): 455–464.
- BSI (British Standard Institution)., 2006. BS EN 1729-1: 2006 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions. UK: BSI.

- Castellucci, H. I., Arezes, P. M., Viviani, C. A., 2010. Mismatch Between Classroom Furniture and Anthropometric Measures in Chilean Schools. *Applied Ergonomics* 41 (4): 563–568.
- Chaffin, D., Anderson, G., 1991. *Occupational Biomechanics*, 2nd edition. New York: John Wiley.
- Chung, J., Wong, T., 2007. Anthropometric evaluation for primary school furniture design. *Ergonomics* 50 (3): 323-334.
- Cotton, L. M., O'Connell, D. G., Palmer, P. P., Rutland, M. D., 2002. Mismatch of school desks and chairs by ethnicity and grade level in middle school. *Work: A Journal of Prevention, Assessment & Rehabilitation* 18 (3): 269–280.
- Dianat, I., Ali Karimib, M., Asl Hashemic, A., Bahrampour, S., 2013. Classroom furniture and anthropometric characteristics of Iranian high school students: Proposed dimensions based on anthropometric data. *Applied Ergonomics* 44 (1): 101–108.
- Evans, W. A., Courtney, A. J., Fok, K. F., 1988. The design of school furniture for Hong Kong school children: an anthropometric case study. *Applied Ergonomics* 19 (2): 122-134.
- Feng, Y., Grootenb, W., Wretenbergc, P., Arborelius, U. P., 1997. Effects of arm support on shoulder and arm muscle activity during sedentary work. *Ergonomics* 40 (8): 834 - 848.
- Garcia-Acosta, G., Lange-Morales, K., 2007. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric costs. *Ergonomics* 50 (10): 1626–1642.
- García-Molina, C., Moraga, R., Tortosa, L., Verde, V., 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico*. Valencia: Instituto Biomecánico de Valencia.
- Gouvali, M. K., Boudolos, K., 2006. Match between school furniture dimensions and children's anthropometry. *Applied Ergonomics* 37 (6): 765-773.
- Grimmer, K., Williams, M., 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics* 47 (4): 416-426.
- Helander, M., 1997. Anthropometry in workstation design. In M. Helander (Ed.), *A Guide to the Ergonomics of Manufacturing*. London: Taylor & Francis.
- Herzberg, H. T. E., 1972. Engineering anthropology. In: *Human engineering guide to equipment design*: Van Cott, H.P., and Kincade, R.D. New York: McGraw-Hill.
- Hira, D. S., 1980. An ergonomic appraisal of educational desks. *Ergonomics* 23 (3): 213-221.
- INN (Instituto Nacional de Normalización Chile), 2002. Norma Chilena 2566. *Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales*. Santiago: INN.
- Jayarathne, I. L. K., Fernando, D. N., 2009. Ergonomics related to seating arrangements in the classroom: Worst in South East Asia? The situation in Sri Lankan school children. *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4): 409–420.

- Jayarathne, K., 2012. Inculcating the Ergonomic Culture in Developing Countries: National Healthy Schoolbag Initiative in Sri Lanka. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54 (6): 908-924.
- Khalil, T. M., Abdel-Moty, E. M., Rosomoff, R. S., Rosomoff, H.L., 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. New York: Van Nostrand Reinhold.
- Koskelo, R., Vuorikari, K., Hänninen, O., 2007. Sitting and standing postures are corrected by adjustable furniture with lowered muscle tension in high-school students. *Ergonomics* 50 (10): 1643-1656.
- Kroemer, K. H. E., Grandjean, E., 1997. *Fitting the task to the human. A textbook of occupational Ergonomics*. 5th edition London: Taylor & Francis.
- Lueder, R., Berg Rice, V., 2008. *Ergonomics for children*. London: Taylor & Francis.
- Milanese, S., Grimmer, K., 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics* 47 (4): 416-426.
- Mokdad, M., Al-Ansari, M., 2009. Anthropometrics for the design of Bahraini school furniture. *International Journal of Industrial Ergonomics*, 39(5), 728–735.
- Molenbroek, J., Ramaekers, Y., 1996. Anthropometric design of a size system for school furniture. In S.A. Robertson (Ed.), *Proceedings of the Annual Conference of the Ergonomics Society: Contemporary Ergonomics*. London: Taylor & Francis.
- Molenbroek, J. F. M., Kroon-Ramaekers, Y. M. T., Snijders, C. J., 2003. Revision of the design of a standard for the dimensions of school furniture. *Ergonomics* 46 (7): 681-694.
- Murphy, S., Buckle, P., Stubbs, D., 2007. A cross-sectional study of self-reported back and neck pain among English schoolchildren and associated physical and psychological risk factors. *Applied Ergonomics* 38 (6): 797–804.
- Musa, A., 2011. Anthropometric evaluations and assessment of school furniture design in Nigeria: A case study of secondary schools in rural area of Odeda, Nigeria. *International Journal of Industrial Engineering Computations* 2: 499–508.
- Occhipinti, E., Colombini, D., Molteni, G., Grieco, A., 1993. Criteria for the ergonomic evaluation of work chairs. *Le Medicina del Lavoro* 84 (4): 274-285.
- Occhipinti, E., Colombini, D., Frigo, C., Pedotti, A., Grieco, A., 1985. Sitting posture: analysis of lumbar stresses with upper limbs supported. *Ergonomics* 28 (9): 1333-1346.
- Orborne, D. J., 1996. *Ergonomics at Work: Human Factors in Design and Development*. 3rd edition. Chichester: John Wiley & Sons.
- Oyewole, S. A., Haight, J. M., Freivalds, A., 2010. The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *International Journal of Industrial Ergonomics*, 40(4), 437–447.

- Panagiotopoulou, G., Christoulas, K., Papanickolaou, A., Mandroukas, K., 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics* 35 (2): 121-128.
- Parcells, C., Stommel, M., Hubbard, R.P., 1999. Mismatch of classroom furniture and student body dimensions. *Journal of Adolescent Health* 24 (4): 265–273.
- Pheasant, S., 1984. *Anthropometrics: An introduction for schools and colleges* (PP7310). London: British Standards Institution.
- Pheasant, S., 1991. *Ergonomics, Work and Health*. Hong Kong: Macmillan.
- Pheasant, S., 2003. *Bodyspace*. 2nd edition. London: Taylor & Francis.
- Ramadan, M. Z., 2011. Does Saudi school furniture meet ergonomics requirements? *Work: A Journal of Prevention, Assessment & Rehabilitation* 38 (2): 93–101.
- Saarni, L., Nygård, C. H., Kaukiainen, A., Rimpelä, A., 2007. Are the desks and chairs at school appropriate? *Ergonomics* 50 (10): 1561–1570.
- Sanders, M. S., McCormick, E. J., 1993. *Applied anthropometry, work-space design and seating* In *Human Factors in Engineering and Design*. 7th edition. Singapore: McGraw-Hill.
- Savanur, C. S., Altek, C. R., De, A., 2007. Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics* 50 (10): 1612-1625.
- Slot, T., Charpentier, K., Dumas, G., Delisle, A., Leger, A., Plamondon, A., 2009. Evaluation of forearm support provided by the Workplace Board on perceived tension, comfort and productivity in pregnant and non-pregnant computer users. *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (1): 67-77.
- UNESCO Santiago, Ministerio de Educación de Chile., 2001. *Guía de recomendaciones para el diseño del mobiliario escolar Chile*. Santiago: UNESCO, MINEDUC.
- Van Niekerk, S., Louw, Q. A., Grimmer-Somers, K., Harvey, J., Hendry, K. J., 2013. The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school. *Applied Ergonomics* 44 (3): 366–371.
- Wingrat, J. K., Exner, C. E., 2005. The impact of school furniture on fourth grade children's on-task and sitting behavior in the classroom: A pilot study. *Work: A Journal of Prevention, Assessment & Rehabilitation* 25 (3): 263-272.
- Yeats, B., 1997. Factors that may influence the postural health of schoolchildren (K-12). *Work: A Journal of Prevention, Assessment & Rehabilitation* 9 (1): 45-55.
- Zacharkow, D., 1987. *Posture: Sitting, Standing, Chair Design & Exercise*. Springfield: Charles C. Thomas.

CHAPTER 4| Applying different equations to evaluate the level of mismatch between students and school furniture

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The mismatch between students and school furniture is likely to result in a number of negative effects, such as uncomfortable body posture, pain, and ultimately, it may also affect the learning process. This study's main aim is to review the literature describing the criteria equations for defining the mismatch between students and school furniture, to apply these equations to a specific sample and, based on the results, to propose a methodology to evaluate school furniture suitability. The literature review comprises one publications database, which was used to identify the studies carried out in the field of the abovementioned mismatch. The sample used for testing the different equations was composed of 2,261 volunteer subjects from 14 schools. Fifteen studies were found to meet the criteria of this review and 21 equations to test 6 furniture dimensions were identified. Regarding seat height, there are considerable differences between the two most frequently used equations. Although seat to desk clearance was evaluated by knee height, this condition seems to be based on the false assumption that students are sitting on a chair with a proper seat height. Finally, the proposed methodology for suitability evaluation of school furniture should allow for a more reliable analysis of school furniture.

Keywords: equation, school, furniture, anthropometry, mismatch.

4.1. Introduction

School furniture is not the only cause of pain and discomfort reported by school children. However, being seated for a long period of time in school furniture is being associated with reports of musculoskeletal discomfort and pain (Fallon and Jameson, 1996). Also, school furniture dimensions, within the context in which it is used, may have an impact on some physical aspects of the students. For example, the high level of mismatch between students and school furniture is being associated with adolescent low back pain (Milanese and Grimmer, 2004). A relationship between furniture mismatch and postural overload is also reported by Batistão (2010), because when the seat height is low, students increase upper back left

inclination and right upper arm elevation, and when the seat is short, students decrease the upper back flexion velocity and increase right upper arm elevation.

Furthermore, Sents and Marks (1989) show, in a laboratory setting, that all children earned higher scores on the intelligence test when seated in furniture that suited their body sizes compared to bigger sized school furniture. This finding was corroborated by Wingrat and Exner (2005), when students were seated in 2 different sizes: traditional classroom furniture and appropriately sized desks and chairs. Smith-Zuzovsky and Exner (2004) reveals that students from 6 and 7 years old, who were seated in furniture that fit them well, performed significantly better on the manipulation test than those who were seated in furniture that was too big for them.

The above situation reveals the great importance of defining school furniture dimensions in an appropriate way. Despite that, there is a large number of studies worldwide that show a clear mismatch between anthropometrics characteristics and the dimensions of school furniture (e.g., Afzan et al., 2012; Castellucci et al. 2010; Chung and Wong, 2007; Dianat et al., 2013; Gouvali and Boudolos, 2006; Molenbroek et al., 2003; Panagiotopoulou et al., 2004; Parcels et al., 1999; Saarni et al., 2007). However, Gouvali and Boudolos (2006) state that the equations used to examine the match or mismatch between school furniture and anthropometric dimensions can be problematic in the sense that they are sometimes based on contradictory criteria, originating from theory that has not necessarily been confirmed with research.

The main aim of this paper is to review literature that describes the criteria equation for defining the mismatch between students and school furniture, to apply the different mismatch equations to a specific sample, and to propose a methodology to evaluate school furniture suitability.

4.2. Method

4.2.1. Literature review

One literature database, Scopus, was used to identify the studies carried out in the field of mismatch or fit between anthropometric measures and classroom furniture. The search terms used were school furniture and classroom furniture (Figure 4.1.).

The inclusion criteria for the selection of the relevant papers are all reviewed articles that are original studies, written in English, and published between January 1980 and January 2013.

The literature review was orientated toward the definition of the mismatch equations. Studies that only present a proposal of a new dimension set size for school furniture, based on, for example, the application of percentiles, were not retained.

Potential mismatch equations were grouped according to the part of the school furniture considered, namely:

- Chair dimensions;
- Interaction between chair and table dimensions.

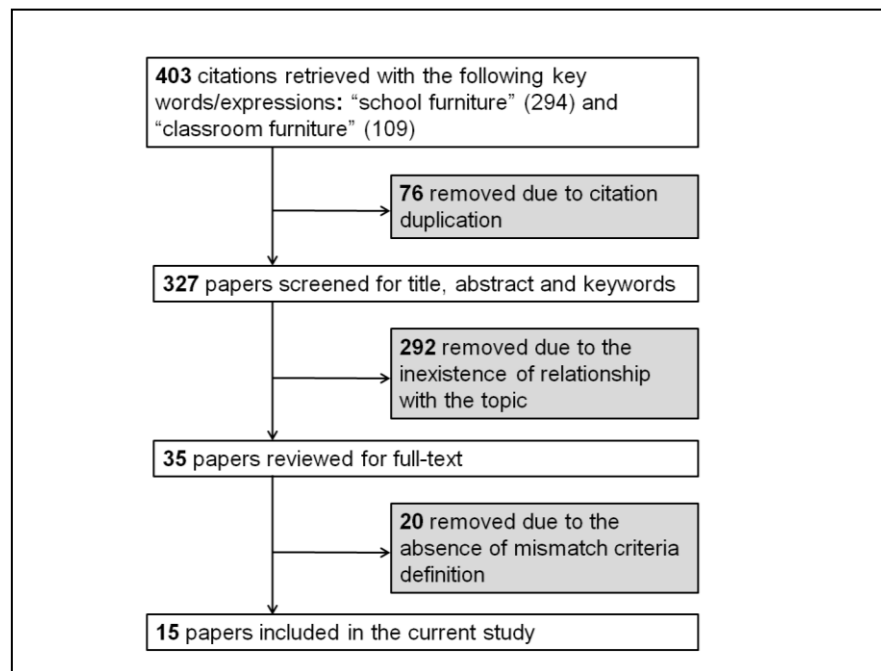


Figure 4.1. Flow diagram of the search strategy

All mismatch equations, one- and two-way, were considered. For those cases where both the minimum and maximum limit were considered, a two-way equation was considered appropriate and for those with only a maximum or a minimum limit, a one-way equation was the required option.

4.2.2. Field procedure

4.2.2.1. Sample

The considered sample involved a group of students, with ages ranging from 5 to 19 years old (11.9 ± 3.5 mean), from basic and secondary schools in the Valparaíso Region of Chile. Fourteen schools were randomly selected from a list given by the Regional Ministerial Secretary of Education and the selection

used a cluster design regarding the three types of elementary school administrations in Chile, as well as of the economic background level of the corresponding students.

The sample study consisted of 2,261 volunteer subjects (1,259 male and 1,002 female). The data collection started after written authorization was obtained about the study from the headmaster of the school, which was followed by the collection of the written authorizations obtained from all parents and students.

4.2.2.2. Anthropometric measurements

The anthropometric measurements were collected from the right side of the subjects, while they were sitting in an erect position on a height-adjustable chair with a horizontal surface, with their legs flexed at a 90° angle, and with their feet flat on the floor or an adjustable footrest. During the measurement process, the subjects were without shoes and wearing light clothing (shorts and t-shirts).

All measurements were taken with a Harpenden standard anthropometer (Holtain Ltd., UK), with an exception made to subjects' stature, which was measured with an estadiometer.

The following anthropometric measures (ISO 7250, 1996) were considered and collected during this study (Figure 4.2.):

Stature: determined as the vertical distance between the floor and the top of the head, and measured with the subject erect and looking straight ahead (Frankfort plane).

Shoulder Height Sitting (SHS): vertical distance from subject's seated surface to the acromion.

Elbow Height Sitting (EHS): taken with a 90° angle elbow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.

Subscapular Height (SUH): the vertical distance from the lowest point (inferior angle) of the scapula to the subject's seated surface.

Popliteal Height (PH): measured with 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface).

Knee Height (KH): estimated using the formula $(PH+TT)*0.9$. This formula was developed using the average and standard deviations of PH, TT, and KH from different databases (Musa, 2011; Pheasant, 2003; Savanur et al., 2007).

Thigh Thickness (TT): the vertical distance from the highest uncompressed point of the thigh to the subject's seated surface.

Hip Width (HW): the horizontal distance measured at the widest point of the hip in the sitting position.

Buttock-Popliteal Length (BPL): taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface.

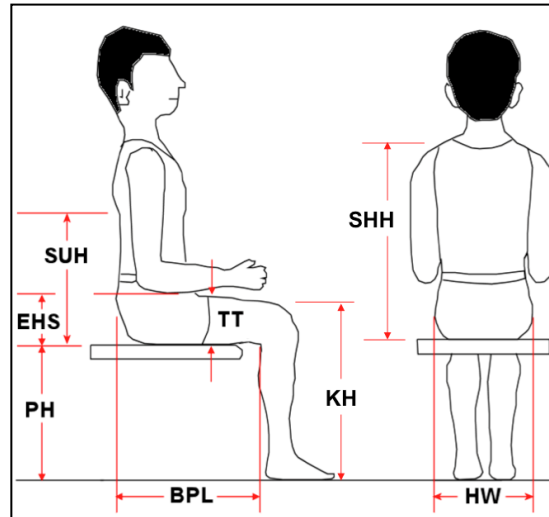


Figure 4.2. Schematic representation of the considered anthropometric measurements

4.2.2.3. School Furniture dimensions

The following furniture dimensions (with the corresponding description) were gathered (Figure 4.3.):

Seat Height (SH): the vertical distance from the floor to the middle point of the front edge of the seat.

Seat Depth (SD): the distance from the back to the front of the sitting surface.

Seat Width (SW): the horizontal distance between the lateral edges of the seat.

Upper Edge of Backrest (UEB): the vertical distance between the middle points of the upper edge of the backrest and the top of the seat.

Desk Height (DH): the vertical distance from the floor to the top of front edge of the desk.

Underneath Desk Height (UDH): the vertical distance from the floor to the lowest structure point below the desk.

Seat Angle: the angle formed by the front part of the seat and the horizontal. It is measured on the median plane, at the angle between the horizontal and the line passing through the upper part of the front edge and the corresponding point at the rear part of the seat (for single sloped seats) or at the top point of the seat (for double sloped seats).

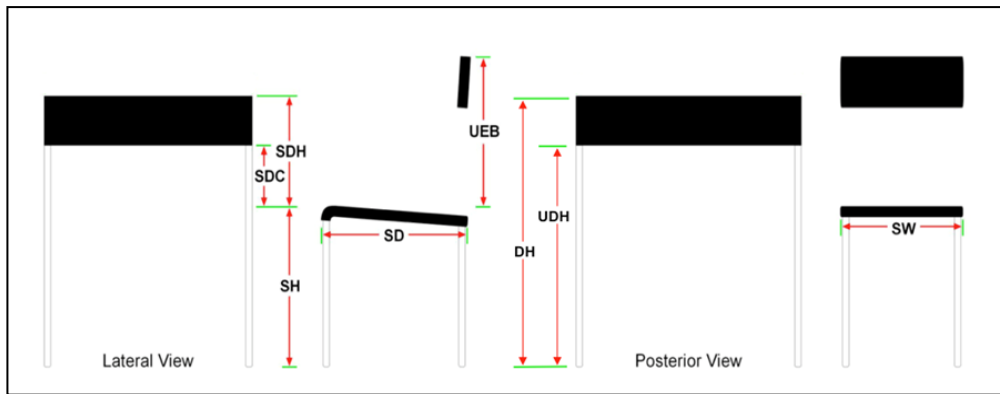


Figure 4.3. Schematic representation of the considered classroom furniture dimensions

4.2.2.4. Statistical analysis

The Kappa statistic was applied to measure the degree of agreement between the different equations. kappa is a good tool to assess inter-rater reliability, particularly for qualitative items (match/mismatch). In this study was used to determine the level of inter-rater reliability of the equations.

In studies where the agreement between two or more observers are an important factor, values can be compared by a statistic that takes into account the fact that observers will sometimes agree or disagree simply by chance. The kappa statistic (or kappa coefficient) is the most commonly used statistic for this purpose (Viera and Garrett, 2005). A kappa of 1 indicates perfect agreement, whereas a kappa of 0 indicates agreement equivalent to chance.

4.3. Results and Discussion

4.3.1. Criteria equation for mismatch

Fifteen studies were found to meet the criteria described above (Figure 4.1.). The results from the studies are as follows:

4.3.1.1. Chair dimensions

Seat Height (SH): this can be considered the most important dimension for the development of a mismatch criterion, since all the studies considered in this review applied an equation to test the fit of SH (Table 4.1.). Also, it should be considered as the starting point and the most important variable for the design of the classroom furniture (Molenbroek et al., 2003; Castellucci et al., 2010). Regarding this dimension, two main equations can be found in the literature (Table 4.1.). One is based on the biomechanics of the knee (Eq.1), considering that SH needs to be lower than PH so that the lower leg forms a 5° - 30° angle relative to the vertical and that the angle range will permit the student to sit in a

chair high enough so that both feet are placed on the floor. On the other hand, the seat should be low enough to avoid an extension of more than 30° relative to the vertical in the knee joint. This is very important since with more extension, the feet will not be placed flat on the floor or the thighs would not be supported enough, generating discomfort.

The other equation includes 2 options (Eq. 2 and Eq. 3), but both are based on the fact that SH has to be evaluated in relation to the PH percentage.

In the three different equations, a two-way mismatch criterion is considered. Only one equation (Eq. 1) considers the use of shoe correction (SC).

Seat Depth (SD): this was used in the majority of the studies (14), being the second most common measurement. This furniture dimension can be evaluated using two equations that use the principle of percentage, but differ in the percentage of Buttock Popliteal Length (BPL) that is considered. This difference only affects the high limit of the equations in 4%, with 95% of the BPL and 99% of the BPL for equations 4 and 5, respectively (Table 4.1.).

Seat Width (SW): this was applied in a few studies (Table 4.1.) and can be tested by two equations. Both equations consider that SW should be higher than Hip Width (HW), and consequently, both equations take low limit or low mismatch into account. Moreover, equation 7 suggests that SW should be at least 10%, but not more than 30% larger than HW in order to provide proper seating, while making an economic use of space.

Upper Edge of Backrest (UEB): one- and two-way limit equations were found for calculating these dimensions. Equation 8 is based on the percentage of SHS. However, none of the studies explain in detail why they used 60% and 80% of SHS. In order to avoid the compression of the scapula and a reduction in arm and trunk mobility (Garcia-Acosta and Lange-Morales 2007, Orborne, 1996), equation 9 is based on a one-way equation and tests if Subscapular Height (SUH) is higher than UEB.

4.3.1.2. Interaction between chair and table dimensions.

Underneath Desk Height (UDH): this was evaluated in 7 studies and the equivalent dimension, Seat to Desk Clearance (SDC), which is obtained from the difference between UDH and SH, was only used once (Table 4.2.). Both of these dimensions, UDH and SDC, reveal a great diversity of approaches and, consequently, of equations. Furthermore, three anthropometric measures can be used to define the level of furniture mismatch (TT, PH, and KH).

UDH has to be large enough in order to allow the students to push the chair under the table and to have enough space to allow leg movement. Accordingly, equations 10, 11, and 13 propose that the desk clearance should be 2 cm higher than KH. In addition, equation 13 allows for shoe correction (SC) and it raises the very interesting point that the high limit used tries to solve one of the major problems regarding two main school furniture dimensions, UDH and DH. This high limit assumes that UDH cannot be higher than the maximum DH minus the table thickness. This problem will be discussed at the end of this section. Equation 12 considers SDC appropriate when it is higher than TT. Equation 14 paints an unclear picture when one takes into consideration that 20 cm is (proportionally) a very different amount for students of 6 or of 17 years old.

Desk Height (DH): this is the furniture dimension with the greatest number of equations in the literature. However, most of these were based on EHS, as the minimum height of DH. Also, the maximum DH, with the exception of equation 17, depends on shoulder flexion and shoulder abduction angles of 25° and 20°, respectively (Chaffin and Anderson, 1991). Most of the equations are two-way, with the exceptions of equations 18 and 19, which only considered the high mismatch. This might be a mistake, in the authors' opinion, since a low mismatch in this equation may originate an increase on spinal loading (Occhipinti et al., 1985). Equation 15 is based on the assumption that students were sitting in a chair with a proper SH, which does not seem to be realistic. Equation 17 is established to test the high limit and a flat 5 cm is added to every EHS, this may lead to some problems since the angles of abduction and flexion of the shoulder joint will not be the same for students with different EHS and SHS. Equations 16, 20, and 21 are quite similar but they do differ in certain respects. The latter two equations include the seat height, while equation 16 tests SDH. Additionally, the backward slope of the chairs is considered in equation 21, since the elbow is aligned with the back of the seat and it is lower than the front edge.

4.3.2. Field results

4.3.2.1. Anthropometric measures

The descriptive statistics of the ten anthropometric dimensions of the students from the fourteen different schools are presented in table 4.3.

4.3.2.2. School Furniture dimensions

Before presenting and analyzing the school furniture of the different schools, it is important to mention that the sample included primary schools (1st to 8th grade, age 6-12), secondary schools (9th to 12th grade, age 13-18) and others with both levels. Due to this variability, some differences were observed regarding the number and type of desks and chairs that exist in each school. The different number of furniture types ranged from 1 to 4 and are represented in table 4.4.

Table 4.1. Summary of the Criteria Equations for mismatch regarding chair dimensions.

Dimension	Equation	Author and year
SH	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$	Afzan, 2012; Agha, 2010; Castellucci et al., 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006.
	Eq. 2: $0.88PH \leq SH \leq 0.95PH$	Batistão et al., 2010; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcels et al., 1999; Ramadan, 2011; Van Niekerk et al., 2013.
	Eq. 3: $0.80PH \leq SH \leq 0.99PH$	Ramadan, 2011.
SD	Eq. 4: $0.80BPL \leq SD \leq 0.95BPL$	Afzan, 2012; Agha, 2010; Batistão et al., 2010; Brewer et al., 2009; Castellucci et al., 2010; Chung and Wong, 2007; Cotton et al., 2002; Dianat et al., 2013; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcels et al., 1999; Van Niekerk et al., 2013.
	Eq. 5: $0.80BPL \leq SD \leq 0.99BPL$	Gouvali and Boudolos, 2006.
SW	Eq. 6: $HW < SW$	Afzan, 2012; Castellucci et al., 2010.
	Eq. 7: $1.1HW \leq SW \leq 1.3HW$	Dianat et al., 2013; Gouvali and Boudolos, 2006; Van Niekerk et al., 2013.
UEB	Eq. 8: $0.6SHS \leq UEB \leq 0.8SHS$	Afzan, 2012; Agha, 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006.
	Eq. 9: $SUH \geq UEB$	Castellucci et al., 2010.

Table 4.2. Summary of the Criteria Equations for mismatch regarding the interaction between chair and table dimensions.

Dimension	Equation	Author and year
SDC or UDH	Eq. 10: $KH + SC + 2 < UDH$	Agha, 2010.
	Eq. 11: $KH + 2 < \bar{U}DH$	Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Panagiotopoulou et al., 2004; Parcels et al., 1999.
	Eq. 12: $TT + 2 < SDC$	Castellucci et al., 2010.
	Eq. 13: $(KH + SC) + 2 \leq UDH \leq [(PH + SC) \cos 5^\circ] + (EHS * 0.8517) + (SHS * 0.1483) - 4$	Gouvali and Boudolos, 2006.
	Eq. 14: $PH + 20 < UDH$	Jayaratne and Fernando, 2009; Jayaratne, 2012.
DH or SDH	Eq. 15: $EHS + [(PH + CS) \cos 30^\circ] \leq DH \leq [(PH + CS) \cos 5^\circ] + EHS * 0.8517 + SHS * 0.1483$	Afzan, 2012; Agha, 2010; Gouvali and Boudolos, 2006.
	Eq. 16: $EHS \leq SDH \leq EHS * 0.8517 + SHS * 0.1483$	Batistão et al., 2010; Brewer et al., 2009.
	Eq. 17: $EHS \leq SDH \leq EHS + 5$	Castellucci et al., 2010; Dianat et al., 2013.
	Eq. 18: $(SH + EHS * 0.8517 + SHS * 0.1483) - DH < 0$, desk is too high	Chung and Wong, 2007.
	Eq. 19: $\{(EHS * 0.8517 + SHS * 0.1483) + [SH - (\sin X^\circ SD)]\} - DH < 0$, desk is too high	Cotton et al., 2002.
	Eq. 20: $SH + EHS \leq DH \leq SH + EHS * 0.8517 + SH * 0.1483$	Panagiotopoulou et al., 2004; Ramadan, 2011.
	Eq. 21: $[SH - (\sin X^\circ SD)] + EHS \leq DH \leq [SH - (\sin X^\circ SD)] + EHS * 0.8517 + SHS * 0.1483$	Parcels et al., 1999.

Table 4.3. Anthropometric measures of the considered sample.

Anthropometric dimensions (cm)	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years
	n:136	n:154	n:162	n:199	n:186	n:214	n:229	n:192	n:182	n:170	n:196	n:156	n:85
Stature	119.7±4.7	125.5±5.1	131.4±5.5	137.0±6.4	142.8±6.8	147.7±7.0	152.8±7.6	157.4±6.5	161.7±8.1	164.3±8.6	164.7±7.9	165.9±8.2	167.3±7.9
Shoulder Height Sitting	40.9±2.3	43.0±2.4	45.1±2.5	47.1±2.8	49.2±3.1	51.2±3.3	52.8±3.2	54.6±3.0	56.8±3.5	57.6±3.7	58.0±2.9	58.9±3.2	58.9±4.0
Elbow Height Sitting	16.9±2.2	17.9±2.2	18.2±2.0	19.0±2.2	19.6±2.7	20.1±2.5	21.1±2.6	21.5±2.9	23.1±2.8	23.6±3.1	24.1±2.7	24.8±3.0	24.7±2.7
Subscapular Height	30.3±2.1	32.2±2.3	33.6±2.2	34.9±2.6	36.4±2.4	37.8±3.0	39.5±2.9	40.6±2.8	42.4±2.9	43.3±2.9	43.6±2.3	44.0±2.7	44.5±2.8
Popliteal Height	29.7±1.6	32.2±1.8	34.1±1.8	35.8±1.9	37.4±2.0	38.6±2.0	39.6±2.1	40.7±1.9	41.5±2.5	41.9±2.7	41.9±2.6	42.0±2.5	42.2±2.1
Knee Height	41.0±2.3	43.6±2.5	46.0±2.6	48.4±2.8	50.4±3.0	52.3±3.0	54.0±3.3	55.3±2.8	56.6±3.5	57.3±3.5	57.5±3.6	57.4±3.4	57.9±3.0
Thigh Thickness	11.3±1.4	11.4±1.6	11.9±1.5	12.6±1.7	12.9±1.7	13.6±1.8	14.3±1.9	14.6±1.7	15.1±2.0	15.4±1.9	15.6±2.0	15.5±2.0	15.7±1.8
Hip Width	26.1±2.3	27.3±2.9	28.6±2.7	30.1±3.0	31.1±3.3	32.4±3.3	33.6±3.6	34.7±3.5	35.7±3.4	36.1±3.4	36.4±3.2	37.3±3.5	36.5±3.2
Buttock Popliteal Length	33.4±1.9	35.2±2.1	37.4±2.4	39.3±2.4	41.0±2.6	43.0±2.8	44.2±3.0	45.6±2.6	46.2±2.8	46.6±2.7	46.8±2.6	47.3±2.6	47.2±2.6

Table 4.4. School furniture dimensions of the considered sample.

School	Type of furniture	Grade	SH	SW	SD	UEB	UDH	DH	Seat Angle
A	1	1	39.8	35.5	32.6	32	59.6	67.7	0
	2	2 and 3	37.1	35.5	31.2	31.5	57	65.1	0
	3	4 to 8	40.5	36.5	36.5	34.8	57	75.6	0
B	1	9 to 12	44	38	38	36	59	76	0
C	1	1 and 2	33	38	38	36	58	63	4° backward slope
	2	3 and 4	40	38	38	36	63	70	4° backward slope
	3	5 to 12	43	35.5	35.5	38	59.5	74	4° backward slope
D	1	1 and 2	38	38	33	32	56	63	4° backward slope
	2	3 to 6	41	40	39	37	61	68	4° backward slope
	3	7 to 12	45	40	39	37	66	73	4° backward slope
E	1	1 and 2	42	35	35	39.5	56	70.5	0
	2	3 to 8	41.5	35.5	35	39.5	58.5	75.5	0
F	1	1 to 12	42.8	36	36	35	56.8	74.2	0
G	1	1	37	35	33	34.7	46.3	63.5	5° backward slope
	2	2 to 8	43.5	36	36	36	57	75	5° backward slope
H	1	1 to 4	38	35	33	34.7	51.7	69	0
	2	5 to 8	43.5	35.5	35.5	37.8	61.7	75	0
I	1	1 to 8	42.7	36.2	36.2	36	60.5	75.7	0
J	1	1	40.5	35	33.5	33.5	49	64	5° backward slope
	2	2	44	34.5	34.5	39	54	69.5	5° backward slope
	3	3 and 4	43	34	34	38.5	62	75	5° backward slope
	4	5 to 12	44.5	34	34	34.5	57.5	75.5	5° backward slope
K	1	1 and 2	37	35	32	33	48	63	0
	2	3 to 12	44	35	35	39	60.5	77	0
L	1	1	38	39.5	39.5	32	50	66	0
	2	2 to 12	43.5	38	38	36	59	74	0
M	1	1 and 2	43.5	35.5	35.5	39	53.5	70.5	5° backward slope
	2	3 to 8	43.5	33.5	33.5	39	64	68.5	5° backward slope
N	1	1 and 2	37.5	35	33	36	48	65.5	0
	2	3 to 8	39	36	36	36	54	70	0
	3	9 to 12	42	36	36	36	59	76	0

4.3.3. Application of the different criteria equation for mismatch

After replacing the existing classroom furniture dimensions in each mismatch criterion equation, the established limits and the body dimensions of the students were compared.

4.3.3.1. Seat Height

It is important to mention, that 2 cm of shoe sole was considered. As expected, there are differences in the results of the three different equations (Figure 4.4.). Furthermore, there are considerable differences between the two most frequently used equations (Eq. 1 and Eq. 2). The result of Kappa Statistics shows slight ($k=0.12$) and fair ($k=0.38$) agreement between equation 1 with equations 2 and 3, respectively.

To improve the analysis, shoe correction (SC) was considered for equations 2 and 3. This discrepancy in the results was reduced and the result of Kappa statistics shows moderate ($k=0.46$) and almost perfect agreement ($k=0.91$) between equations 1 with equation “2 with SC” and “3 with SC”, respectively.

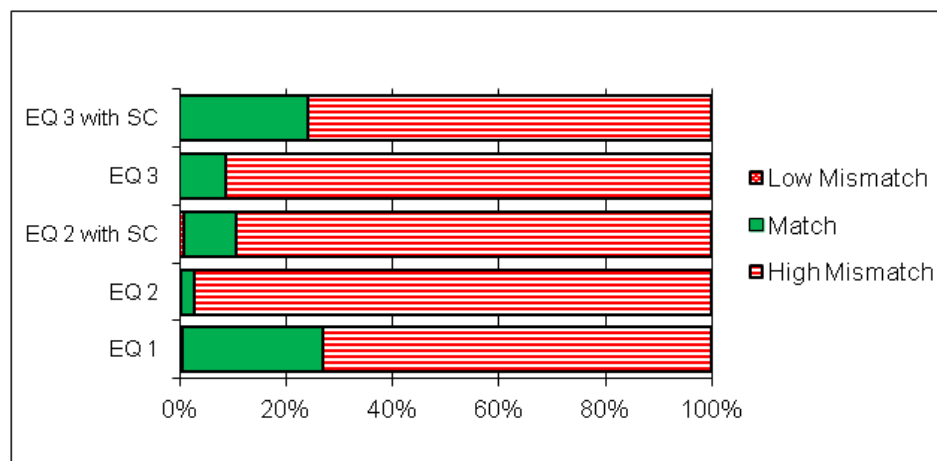


Figure 4.4. Results of Equations regarding Seat Height

Since the anthropometric measurements in the all studies were made without shoes, the non-consideration of SC appears to affect the overall results in the different studies that applied equations 2 and 3. The conclusions of those studies appears to overestimate the number of students using a higher seat, a situation where the students would not be able to rest their feet on the floor, generating increasing pressure on the tissue of the posterior surface of the knee (García-Molina et al., 1992; UNESCO, 2001; Milanese and Grimmer, 2004)

Finally, even though equations 2 and 3 are based on the same principles, the results of the mismatch show differences between them since equation 3 is less strict. Kappa statistics indicates a moderate agreement between equations 2 and 3 ($k=0.44$).

4.3.3.2. Seat Depth

Figure 4.5. shows that 7% of high mismatch is the difference between the results of the two equations. On the other hand, the lower limit and the results of low mismatch remain the same for the two equations. The slight difference is confirmed by the result of an almost perfect agreement between equations ($k=0.82$). Despite the Kappa results, considering the high limit of equation 5, the students could have a space corresponding to 1% of their BPL between the front edge of the seat and the popliteal region. Using the sample from this research, the space mentioned before will be between 2.8 and 5.4 millimeters, which is too small if one considered the fact that the anthropometric measurements were made with the students using shorts, like most of the reviewed studies. When wearing regular clothes, the students could be in a more uncomfortable situation mainly due the compression of the popliteal surface. Furthermore, to avoid this situation, students will sit forward and will not be able to use the backrest of the seat in a proper way (Milanese and Grimmer, 2004). This erroneous use of the backrest would most likely generate a kyphotic posture (Khalil et al. 1993, Pheasant 1991).

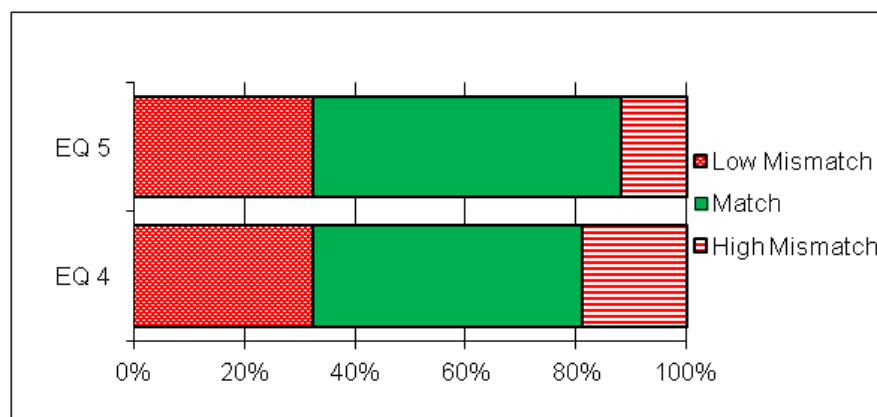


Figure 4.5. Results of Equations regarding Seat Depth

4.3.3.3. Seat Width

Figure 4.6. shows almost double the level of low mismatch in equation 7 when compared to equation 6. The results of Kappa statistics show a moderate agreement range between equations 6 and 7 ($k=0.51$), where the difference is due to a margin of 10% in equation 7. It is important to mention that the high mismatch was not considered in the Kappa statistic and can be considered to be of secondary importance due to the fact that it mostly affects the optimization of the space used rather than the student's seating

posture. Finally, it can be concluded that equation 7 is a stricter equation since it uses a margin of 10%. It seems relevant to highlight that this margin is more important for office chairs than for school chairs due to the more frequent use of arm support in the former case.

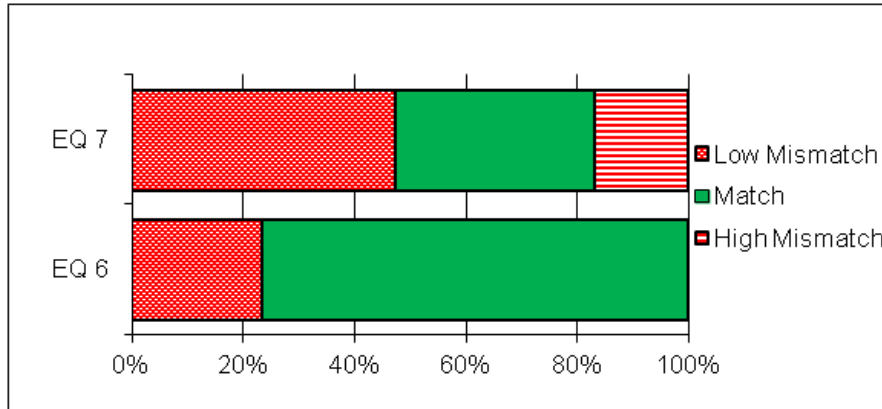


Figure 4.6. Results of Equations regarding Seat Width

4.3.3.4. Upper edge of Backrest

Figure 4.7. presents the results of equations 8 and 9. Taking into consideration that equation 9 only has one limit, the results of mismatch are presented only as high mismatch. In this respect, it is possible to observe some differences between the results of these equations. Furthermore, the results of the Kappa statistic show a moderate agreement ($k=0.43$). Lastly, equation 8 needs to be analyzed more carefully since it assumes that UEB should be between 60% and 80% of the SHS. However, in the reviewed studies citing this equation (see table 4.1.) there is no detailed explanation or justification for the use of these limits percentage values. In authors' opinion, it is possible that 80% of SHS is at the higher limit of the UEB and, in this case, it can be considered similar to SUH in equation 9. Paired Sample T-Tests (with 95% confidence intervals) were performed to examine the differences between 80% of SHS and SUH, considering the whole sample. The obtained results show that the values of 80% of SHS are significantly higher than SUH ($t=7.3$; $p=0.001$). This situation is reflected in the low levels of high mismatch from equation 8 (Figure 4.7.). Additionally, the low limit considered in equation 8 is somehow difficult to understand because the main problem is when UEB is higher than SUH. It is also important to mention that there is an interaction between UEB and the Lowest Edge of Backrest (LEBR), as well as with the Height of Backrest (HBR).

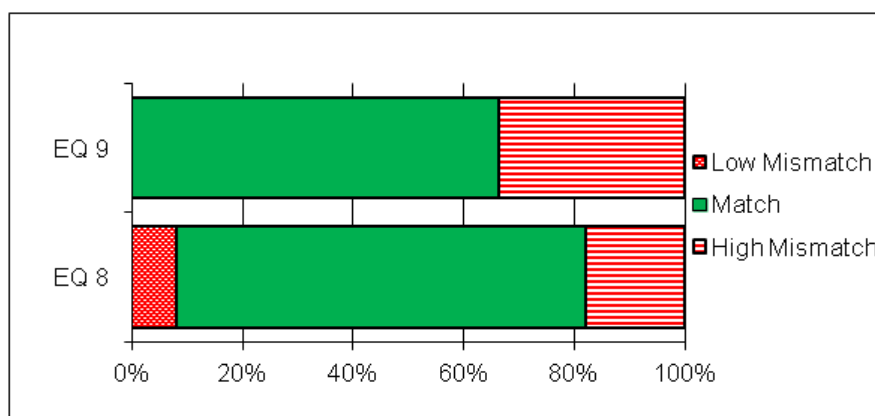


Figure 4.7. Results of Equations regarding Upper Edge of Backrest

4.3.3.5. Underneath Desk Height or Seat to Desk Clearance

Figure 4.8. shows that the equations 10, 11, and 13 present the lowest level of mismatch, since those equations consider KH as the highest point of the lower limbs and compare this with UDH. Those equations seem to be based in the erroneous assumption that KH is higher than SH+TT. Furthermore, the majority of the students, like in most of the studies reviewed, were using a high seat (Figure 4.4.), which will increase the difference between SH+TT and KH. Equation 12 reveals a 52% mismatch since it compares SDC to TT. The result of Kappa statistics shows a slight agreement between equations 12 and 10 ($k=0.11$), between 12 and 11 ($k=0.03$), and between 12 and 13 ($k=0.11$). Despite the similar levels of mismatch in equations 12 and 14, the Kappa statistics shows a moderate agreement between them ($k=0.52$). Also, the principles of equation 14 are wrong since they take into consideration the PH of the students, the measure used to define the SH, adding 20 cm flat, which is proportionally very different for students in the range of 6 to 17 years old.

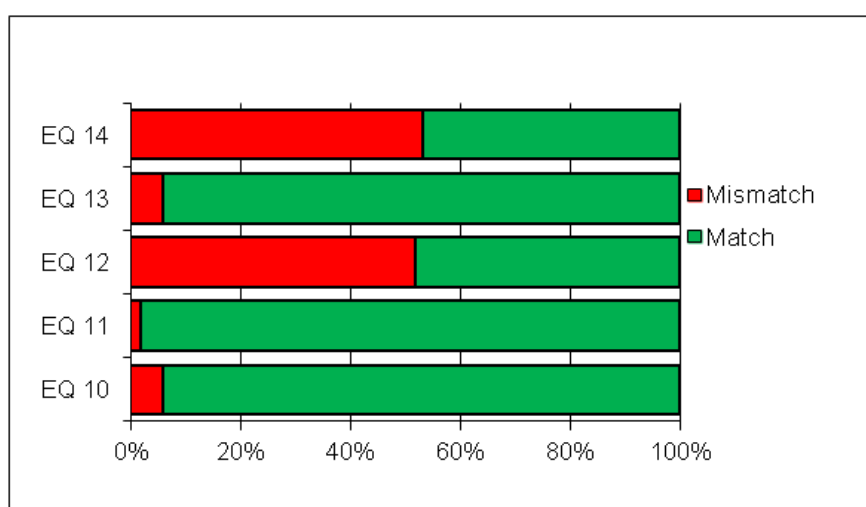


Figure 4.8. Results of Equations regarding Underneath Desk Height or Seat to Desk Clearance

4.3.3.6. Desk Height or Seat to Desk Height

From Figure 4.9, it is possible to observe that there are very high levels of high mismatch, but not many differences between the considered equations. Equations 16 and 20 present a perfect agreement ($k=1$), since those equations are similar, except that they evaluate SDH and DH, respectively. Equations 19 and 21 have the same level of high mismatch and the Kappa statistics shows an almost perfect agreement ($k=0.99$). Although, it is important to emphasize that equation 19 only tests the high mismatch. The consideration of backward slope in equations 19 and 21 seems to be the main cause of the differences in the results with equations 16, 18, and 20. As an example, the Kappa statistics show a substantial agreement between equations 21 and 16 ($k=0.68$), between 21 and 18 ($k=0.69$), and between 21 and 20 ($k=0.68$).

Equation 17, the one that uses 5 cm flat to define the high level or the maximum SDH, presents similar results when compared with the other equations. Furthermore, the Kappa statistics of equation 17 show an almost perfect agreement with equations 16 ($k=0.89$), 18 ($k=0.86$), and 20 ($k=0.89$) as well as a substantial agreement with equations 19 ($k=0.59$) and 21 ($k=0.59$). This last result seems to be related to the consideration of backward slope, since the consideration of this aspect in equation 17 leads to a Kappa statistic showing an almost perfect agreement with equation 21 ($k=0.98$). These results suggest that the use of equation 17, considering also the use of the backward slope, can be considered as an alternative to equation 21, in particular when the researcher did not gathered the SHS.

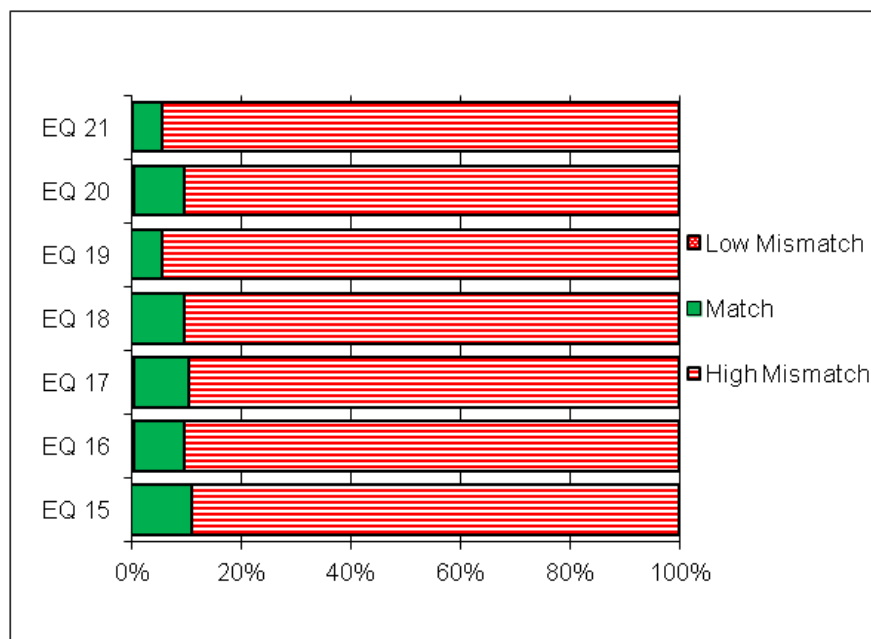


Figure 4.9. Results of Equations regarding Desk Height or Seat to Desk Height

An issue that seems to lead to a very important discussion is the interrelation between the mismatch equations applied to test the fit of DH and UDH. Sometimes the proposed equations can be contradictory, even in ideal conditions. To better explain this situation, it is possible to consider the following assumption: the high limit of Eq. 21 - (SH + Eq. 12 + table thickness) < 0, and that will be the “High Mismatch”. This assumption leads us to the equation 22:

$$\{[SH - (\sin X^\circ SD)] + EHS \cdot 0.8517 + SHS \cdot 0.1483\} - (SH + TT + 2 + 7) < 0, \text{ will be High DH} \quad \text{Eq. (22)}$$

Where 7 cm corresponds to the minimum table thickness considered for the structure in the Chilean Standard 2566 (INN, 2002).

Considering the data of the 2,261 measured students and applying equation 22, the results show that 37% of the students will use a high DH or will have a high mismatch regarding DH. This situation shows that there is a problem in the criteria formulation for some of the presented equations. As it was mentioned before, the design and evaluation of school furniture begins with SH. Secondly, the students need an under table space that should be large enough to push the chair under the table and have enough space to allow for the movement of their legs. Having said that, there are not many changes that can be made to the SDC equation (Eq. 12) since it is a convenient equation for the determination of the needed space. On the other hand, DH or SDH equations need to be evaluated in the field or in laboratory; for example, the criteria presented by Chaffin and Anderson (1991) does not take the elbow or forearm support into consideration, which may be used to reduce the strain on the shoulder (Feng et al., 1997; Slot et al., 2009). Furthermore, there are some authors who suggest that, for writing and drawing with the forearm or elbow supported, the table should be positioned at 10 cm above EHS (Pheasant 2003; Kroemer and Grandjean, 1997). However, as it was mentioned before, this could cause some problems since 10 cm above EHS is not necessarily the same for a student of 6 years or for a student of 18 years old.

4.3.4. Methodology of evaluation of school furniture suitability

This proposed methodology considered the evaluation of six furniture dimensions (Table 4.5). Despite that, there are some main furniture dimensions that have to be considered within this type of research, specifically those that are frequently used in the reviewed studies: SH, SD, SDC, and DH. To apply the

different equations, researchers will have to consider the following anthropometrics measures: PH, BPL, HW, SUH, TT, EHS, and SHS.

The current methodology is based in a bottom-top approach. This requirement stems from the fact that SH is the most important measure for the mismatch criteria. As it was shown before in Figure 4.4, SC needs to be considered in the SH formula. It is also necessary to consider that SC may naturally vary according to culture, fashion, and country. To get more representative values of the sample under study, an option is to measure the shoe heel of the students or measure the shoe heel through a national consumers' survey (Castellucci et al. 2010). If this situation is not possible for the researchers, an alternative option is to consider SC as a value between 2 cm (Agha, 2010; Dianat et al., 2013, Gouvali and Boudolos, 2006) and 3 cm (Castellucci et al. 2010). There are also other authors who recommended SC with values between 2.5 (Herzberg, 1972) and 4.5 cm (Pheasant, 1984).

In the case of SDC, if the researchers have only gathered KH, TT can be estimated with the following equation:

$$(KH-PH)*1.7 \quad \text{Eq. (23)}$$

This equation was developed using the average and standard deviations of PH, TT, and KH from different databases (Musa, 2011; Pheasant, 2003; Savanur et al., 2007). Furthermore, if SDC was not gathered, UDH can be used instead, by applying the following equation:

$$SDC=UDH-SH \quad \text{Eq. (24)}$$

Regarding SDC and DH, it is important to keep in mind, as discussed earlier, that the interrelation between the mismatch equations applied to test the fit of DH and UDH are based on contradictory criteria. Despite this, DH needs to be evaluated with equation 21 (Parcells et al., 1999). To apply this equation properly, the seat angle has to be measured and replace the X° backward slope or negative seat angle. If the seat has a forward slope or positive angle it will be: $SH + SD * \sin X^\circ$.

Finally, it is important to consider the cumulative fit or transversal mismatch, which is defined as the mismatch that takes into account the cumulative values of the different furniture dimensions. This can be considered as a very important indicator of the furniture fit, since it shows how many students are actually matched to the dimensions of their school furniture. The order to apply the cumulative fit is the same as this proposed methodology, i.e., through a bottom-top approach.

Table 4.5. Proposed methodology for evaluating school furniture suitability.

School furniture dimension	Mismatch equation
SH*	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$
SD*	Eq. 4: $0.80BPL \leq SD \leq 0.95BPL$
SW	Eq. 6: $HW < SW$
UEB	Eq. 9: $SUH \geq UEB$
SDC*	Eq. 12: $TT + 2 < SDC$
DH*	Eq. 21: $(SH - (\sin X^\circ SD)) + EHS \leq DH \leq (SH - (\sin X^\circ SD)) + EHS * 0.8517 + SHS * 0.1483$

* Main furniture dimensions

4.4. Conclusion

The results that have been obtained indicate that 6 furniture dimensions are evaluated with a high number of applied equations. For SH, the most evaluated furniture dimension, there are considerable differences between the two most frequently used equations. Additionally, one of these equations does not consider shoe correction. In the case of SD, there are not many differences between the two applied equations. Regarding UEB, the equations are based on principles that are not fully explained by the corresponding authors.

Most of the equations regarding UDH or SDC present one systematic error, which is to assume that students are sitting on a chair with a proper seat height.

It should be also acknowledged that the interrelation between the equations for evaluating the level of mismatch of SDC and DH are based on contradictory criteria and therefore, it will be necessary to develop new equations for these parameters and validate them.

Finally, the proposed methodology for the evaluation of school furniture suitability should allow for a more reliable and accurate analysis of school furniture.

References

- Afzan, Z., Hadi, S., Shamsul, B., Zailina, H., Nada, I., Rahmah, A., 2012. Mismatch between school furniture and anthropometric measures among primary school children in Mersing, Johor, Malaysia. Network of Ergonomics Societies Conference (SEANES), Southeast Asian.
- Agha, S., 2010. School furniture match to students' anthropometry in the Gaza Strip. *Ergonomics* 53 (5), 344–354.

- Batistão, M., Sentanin, A., Moriguchi, S., Hansson, G., Coury, H., Sato, T., 2012. Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs. *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1), 4817-4824.
- Brewer, J., Davis, K., Dunning, K., Succop, P., 2009. Does ergonomic mismatch at school impact pain in school children? *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4), 455–464.
- Castellucci, H., Arezes, P., Viviani, C., 2010. Mismatch Between Classroom Furniture and Anthropometric Measures in Chilean Schools. *Applied Ergonomics* 41 (4), 563–568.
- Chaffin, D., Anderson, G., 1991. *Occupational Biomechanics*, 2nd edition. John Wiley, New York.
- Chung, J., Wong, T., 2007. Anthropometric evaluation for primary school furniture design. *Ergonomics* 50 (3): 323-334.
- Cotton, L., O'Connell, D., Palmer, P., Rutland, M., 2002. Mismatch of school desks and chairs by ethnicity and grade level in middle school. *Work: A Journal of Prevention, Assessment & Rehabilitation* 18 (3), 269–280.
- Dianat, I., Ali Karimib, M., AslHashemic, A., Bahrapour, S., 2013. Classroom furniture and anthropometric characteristics of Iranian high school students: Proposed dimensions based on anthropometric data. *Applied Ergonomics* 44 (1), 101–108.
- Fallon, E., Jameson, C., 1996. An ergonomic assessment of the appropriateness of primary school furniture in Ireland. In A.F. Ozok and G.Salvendy (Eds.), *Advances in Applied Ergonomics*. pp. 770–773. West Lafayette, USA .
- Feng, Y., Grootenb, W., Wretenbergc, P., Arborelius, U., 1997. Effects of arm support on shoulder and arm muscle activity during sedentary work. *Ergonomics* 40 (8), 834 - 848.
- Garcia-Acosta, G., Lange-Morales, K., 2007. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric costs. *Ergonomics* 50 (10), 1626–1642.
- García-Molina, C., Moraga, R., Tortosa, L. , Verde, V., 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico*. Instituto Biomecánico de Valencia, Valencia.
- Gouvali, M., Boudolos, K., 2006. Match between school furniture dimensions and children's anthropometry. *Applied Ergonomics* 37 (6), 765-773.
- Herzberg, H., 1972. Engineering anthropology. In: *Human engineering guide to equipment design*: Van Cott, H.P., and Kincade, R.D. McGraw-Hill, New York.
- INN (Instituto Nacional de Normalización Chile), 2002. Norma Chilena 2566. *Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales*. INN, Santiago de Chile.
- ISO, 1996. ISO 7250: Basic Human Body Measurements for Technological Design. International Organization for Standardization, Geneva, Switzerland.

- Jayarathne, I., Fernando, D., 2009. Ergonomics related to seating arrangements in the classroom: Worst in South East Asia? The situation in Sri Lankan school children. *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4), 409–420.
- Jayarathne, K., 2012. Inculcating the Ergonomic Culture in Developing Countries: National Healthy Schoolbag Initiative in Sri Lanka. *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54 (6), 908-924
- Khalil, T., Abdel-Moty, E., Rosomoff, R., Rosomoff, H., 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. Van Nostrand Reinhold, New York.
- Kroemer, K., Grandjean, E., 1997. *Fitting the task to the human. A textbook of occupational Ergonomics*, 5th edition. Taylor & Francis, London.
- Milanese, S., Grimmer, K., 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics* 47 (4), 416-426.
- Molenbroek, J., Kroon-Ramaekers, Y., Snijders, C., 2003. Revision of the design of a standard for the dimensions of school furniture. *Ergonomics* 46 (7), 681-694.
- Musa, A., 2011. Anthropometric evaluations and assessment of school furniture design in Nigeria: A case study of secondary schools in rural area of Odeda, Nigeria. *International Journal of Industrial Engineering Computations* 2 , 499–508.
- Occhipinti, E., Colombini, O., Frigo, C., Pedotti, A., Grieco, A., 1985. Sitting posture: analysis of lumbar stresses with upper limbs supported. *Ergonomics* 28 (9), 1333-1346.
- Orborne, D., 1996. *Ergonomics at Work: Human Factors in Design and Development*. 3rd edition. John Wiley & Sons, Chichester.
- Panagiotopoulou, G., Christoulas, K., Papanicolaou, A., Mandroukas, K., 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics* 35 (2), 121-128.
- Parcells, C., Stommel, M., Hubbard, R., 1999. Mismatch of classroom furniture and student body dimensions. *Journal of Adolescent Health* 24 (4), 265–273.
- Pheasant, S., 1984. *Anthropometrics: An introduction for schools and colleges* (PP7310). British Standards Institution, London.
- Pheasant, S., 1991. *Ergonomics, Work and Health*. Macmillan, Hong Kong.
- Pheasant, S., 2003. *Bodyspace*, 2nd edition. Taylor & Francis, London.
- Ramadan, M., 2011. Does Saudi school furniture meet ergonomics requirements? *Work: A Journal of Prevention, Assessment & Rehabilitation* 38 (2), 93–101.
- Saarni, L., Nygård, C., Kaukiainen, A., Rimpelä, A., 2007. Are the desks and chairs at school appropriate? *Ergonomics* 50 (10), 1561–1570.

- Savanur, C., Altekari, C., De, A., 2007. Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics* 50 (10), 1612-1625.
- Sents, B., Marks, H., 1989. Changes in preschool children's IQ scores as a function of positioning. *American Journal of Occupational Therapy* 43 (10), 685-687.
- Slot, T., Charpentier, K., Dumas, G., Delisle, A., Leger, A., Plamondon, A., 2009. Evaluation of forearm support provided by the Workplace Board on perceived tension, comfort and productivity in pregnant and non-pregnant computer users. *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (1), 67-77.
- Smith-Zuzovsky, N., Exner, C., 2004. The effect of seated positioning quality on typical 6- and 7-year-old children's object manipulation skills. *American Journal of Occupational Therapy* 58 (4), 380-388.
- UNESCO Santiago, Ministerio de Educación de Chile. 2001. Guía de recomendaciones para el diseño del mobiliario escolar Chile. UNESCO, MINEDUC, Santiago de Chile.
- Van Niekerk, S., Louw, Q., Grimmer-Somers, K., Harvey, J., Hendry, K., 2013. The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school. *Applied Ergonomics* 44 (3), 366–371.
- Viera, A., Garrett, J., 2005. Understanding interobserver agreement: the kappa statistic. *Family Medicine* 37 (5), 360-363.
- Wingrat, J., Exner, C., 2005. The impact of school furniture on fourth grade children's on-task and sitting behavior in the classroom: A pilot study. *Work: A Journal of Prevention, Assessment & Rehabilitation* 25 (3), 263-272.

CHAPTER 5| Evaluation of the match between anthropometric measures and school furniture dimensions in Chile

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BACKGROUND: Students are exposed to the first systematic tasks or activities that a human being carries out in his/her life while at school. In this workplace situation, school furniture is a key factor for the adoption of proper body posture.

OBJECTIVE: The aim of this paper was to observe and determine the potential mismatch between school furniture dimensions and anthropometric characteristics of the students from the Valparaíso region of Chile.

METHODS: The sample consisted of 3,078 volunteer participants from 18 schools (public, semi-public, private). Eight anthropometric measures were gathered, together with six furniture dimensions. Mismatch analyses were carried out by using pre-defined mismatch criteria.

RESULTS: Many different types of school furniture were presented at the schools. Also, a high level of mismatch was registered for seat height, desk height and seat-to-desk clearance. Finally, the analysis of all considered dimensions together showed that there was a high level of cumulative mismatch.

CONCLUSIONS: It can be concluded that there were high levels of mismatch between the school furniture and student anthropometric characteristics and that this mismatch varied within the difference types of schools. This situation may have occurred because furniture acquisition was made without considering any ergonomic criteria.

Keywords: students, anthropometry, classroom, mismatch.

5.1. Introduction

Students are exposed to the first systematic tasks or activities that human beings carry out in their life while at school. Life as a student can be considered as being among the most sedentary occupations [1]. In this workplace situation, school furniture is a key factor for the adoption of proper postures, and

consequently, it has implications for the productivity of students. Learning can also be affected, since uncomfortable and awkward body postures can decrease students' interest in learning, even during the most stimulating and interesting lessons [2]. Static postures and prolonged sitting are two identified risk factors for lower back pain [3].

Studying the workplace and its interaction with workers is one of the main issues in ergonomics, which uses knowledge from different disciplines, such as design, biomechanics and anthropometrics, to solve this problem. There are some studies regarding the impact of the design of school furniture on the musculoskeletal system, such as the fact that the use of a school desk with a tilted table surface seems to result in a reduction in trunk and neck flexion, thereby helping to preserve the natural lordosis in the lumbar and cervical regions of the spine [4]. Other authors, such as Linton et al. [5], verified that the use of chairs with curved seats and a desk with inclination reduced musculoskeletal symptoms (back pain, neck pain, headache and fatigue) in comparison to the use of a desk with a flat top (parallel to the floor) and a detached chair with a straight back and seat placed at a 90° angle. Saarni et al. [6] also demonstrated that the use of individually adjustable saddle-type chairs and desks improved working postures compared to the use of conventional fixed workstations.

Anthropometrics are important in the study of how students and furniture interact, because students change in size considerably during their years at school. However, growth spurts occur at different times for females than males [7]. Also, younger children tend to grow more in their extremities; meanwhile, adolescent growth (following puberty) largely affects the spine [8]. Furthermore, musculoskeletal dysfunctions can increase during high growth stages, such as puberty [9] and young children are at greater risk because their bones are still developing [8]. Finally, it has also been demonstrated that poor sitting habits acquired during childhood are very difficult to change later in adolescence and/or adulthood [10].

These implications may promote the use of adjustable school furniture that will allow a better fit and posture. However, most of the currently used school furniture all over the world has fixed dimensions [11–13], resulting in a clear mismatch between the anthropometric characteristics of the students and the dimensions of the furniture [11–13]. Mismatch is considered here as it was defined previously by other authors, i.e., as an incompatibility between the dimensions of the classroom furniture and the dimensions of the student's body [14].

The high level of mismatch between student anthropometric characteristics and school furniture has been associated with postural overload [15]. A relationship between furniture mismatch and adolescent low back pain has also been reported by Milanese and Grimmer [16]. The use of too low or too high chair and

table heights relative to the student's body dimensions seems to increase the stresses acting on the low back (L5/S1), and their ratings of discomfort associated with sitting [17].

Sents and Marks [18] showed, in a laboratory setting, that all children earned higher scores on the intelligence test when they were seated in furniture that better suited their body sizes compared to school furniture that was too large. Smith-Zuzovsky and Exner [19] revealed that students between 6 and 7 years of age who were seated in furniture that fit them well, performed significantly better on a in-hand manipulation test (IMT), compared to those who were seated in furniture that was too big for them.

A previous study analysing the mismatch between the anthropometric measure and school furniture in Chile has already been published [20]. However, that study had only considered 195 students, all of them from the 8th grade. Therefore, the current study has the benefit of enlarging significantly the sample and the representativeness of the analysis by including in the analysed sample of more than 3,000 students. Additionally, the current sample includes all the students from the 1st to the 12th grade.

Considering the relevance of the mismatch between students and furniture at school, the aim of this paper was to observe and determine the potential mismatch between school furniture dimensions and the student anthropometric characteristics from the Valparaíso region of Chile.

5.2. Methodology

5.2.1. Sample

In Chile student growth seems to be influenced by socio-economic status. It has been observed previously that children of higher socio-economic status are, on average, taller than those of lower and medium socio-economic status [20,21]. Furthermore, in Chile there is a strong relation between family income and school administration type, i.e., children of lower, medium and high socio-economic status tend to attend to public, semi-public and private school, respectively [22]. Due to this, the selection used a stratified random sample design regarding the three types of elementary school administrations in Chile: public school, where parents do not have to pay for their children's studies; semi-public, where both the parents and the government pay for the education; and private school, where all involved costs must be assumed by parents.

The estimated student population of basic and secondary schools in the Valparaíso Region during 2010 was 243,490 students, where 26,2%, 64,6% and 9,2% of the students went to public, semi-public and private schools, respectively. Considering a 50% prevalence of school furniture mismatch ($p=0.5$ to obtain the largest sample), with 3% accuracy, 95% confidence intervals, and 15% of loss, the theoretical sample

size is 1,251 students. However, based on the Chilean school education system, every school has 12 grades, with students ranging from the age of 5 to 19 years old, and in order to cover all of them, it was decided to use a random sample of at least 20 students per grade, keeping the proportionality of each cluster. The real (final) sample, gathered during 2012, came from 18 schools that were randomly selected from a list given by the Regional Ministerial Secretary of Education and involved a group of 3,078 students (1,397 female and 1,681 male), with ages ranging from 5 to 19 years old (11.7 ± 3.5).

The data collection started after written authorization was obtained from the headmaster of the school, which was followed by the collection of the written authorizations from all parents and students.

5.2.2. Anthropometric Measurements

Before starting the measurement process, two groups of university students from the last year of the physiotherapy program underwent a two-week training session, including both theoretical and practical instructions on anthropometric measurement. The training was designed and carried out by two certified ergonomists with several years of experience in collecting anthropometric data. They spent considerable time practicing the measurements to achieve greater consistency between measurers. At the end of the training session, both inter-measurer and intra-measurer reliability were assessed by using Intraclass Correlation Coefficient (ICC) model "two-way mixed" and type "absolute agreement". Correlations were interpreted according to the ranges suggested by Portney and Watkins [23]: $ICC \geq 0.50$ was interpreted as moderate; $ICC \geq 0.75$ was interpreted as strong. The results from Table 5.1. shows that measurers have a strong value of inter- and intra-reliability.

Table 5.1. Intra and Inter-measurer reliability (ICC values)

Measurers	PH	SUH	EHS	BPL	TT	HW	SHS	S
Measurer 1	0.905	0.886	0.874	0.968	0.825	0.878	0.945	0.959
Measurer 2	0.961	0.874	0.902	0.898	0.846	0.915	0.932	0.989
Measurer 3	0.925	0.902	0.861	0.945	0.814	0.898	0.912	0.999
Measurer 4	0.916	0.884	0.842	0.936	0.882	0.912	0.956	0.984
Inter-measurers	0.904	0.845	0.842	0.882	0.812	0.841	0.925	0.974

Popliteal Height (PH), Subscapular Height (SUH), Elbow Height Sitting (EHS), Buttock Popliteal Length (BPL), Thigh Thickness (TT), Hip Width (HW), Shoulder Height Sitting (SHS), Stature (S).

The measurement process was done during the Chilean 2012 academic year (March to December), the range of days spending in each school were from 1 to 4 days depending the amount of students at each

location. Most of the measurements were carried out during the physical education classes. However, some of the students were measured during different classes, such as Math, Music, Spanish and History.

The anthropometric measurements were collected from the right side of the participants, while they were sitting in an erect position on a height-adjustable seat with a horizontal surface, with their legs flexed at a 90° angle, and with their feet flat on the floor or on an adjustable footrest. During the measurement process, the participants were without shoes and wearing light clothing (shorts and t-shirts).

All measurements were taken with a Harpenden standard anthropometer (Holtain Ltd., UK), with an exception made for participants' stature, which was measured with a stadiometer.

The following anthropometric measures were considered and collected during this study [24], which are also illustrated in Figure 5.1.:

- Stature (S): determined as the vertical distance between the floor and the top of the head, and measured with the participant standing and looking straight ahead (Frankfort plane);
- Shoulder Height Sitting (SHS): vertical distance from participant's seated surface to the acromion;
- Elbow Height Sitting (EHS): taken at 90° angle elbow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the participant's seated surface;
- Subscapular Height (SUH): the vertical distance from the lowest point (inferior angle) of the scapula to the participant's seated surface;
- Popliteal Height (PH): measured at 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface);
- Thigh Thickness (TT): the vertical distance from the highest uncompressed point of the thigh to the participant's seated surface;
- Hip Width (HW): the horizontal distance measured at the widest point of the hip in the sitting position;
- Buttock-Popliteal Length (BPL): taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface.

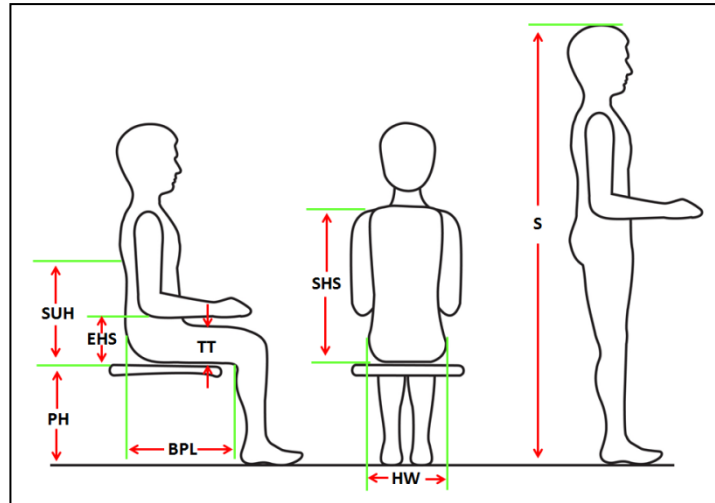


Figure 5.1. Anthropometric dimensions measured in the study.

5.2.3. School Furniture Dimensions

It is important to mention that all the evaluated students in the different schools usually spent the entire school day in just one classroom. They only move to another location for computer and physical education class. Due to this, the school furniture measurement process was done during the use of their normal classroom. The following furniture dimensions, with the corresponding descriptions, were gathered and are presented in Figure 5.2.:

- Seat Height (SH): the vertical distance from the floor to the middle point of the front edge of the sitting surface;
- Seat Depth (SD): the distance from the back to the front of the sitting surface;
- Seat Width (SW): the horizontal distance between the lateral edges of the sitting surface;
- Upper Edge of Backrest (UEB): the vertical distance between the middle points of the upper edge of the backrest and the top of the sitting surface;
- Desk Height (DH): the vertical distance from the floor to the top of the front edge of the desk;
- Seat to Desk Clearance (SDC): the vertical distance from middle point of the front edge of the sitting surface to the lowest structure point below the desk;
- Seat Angle (SA): the angle formed by the front part of the sitting surface and the horizontal. It is measured on the median plane, at the angle between the horizontal and the line passing through the upper part of the front edge and the corresponding point at the rear part of the seat (for single sloped seats) or at the top point of the seat (for front to back double sloped seats).

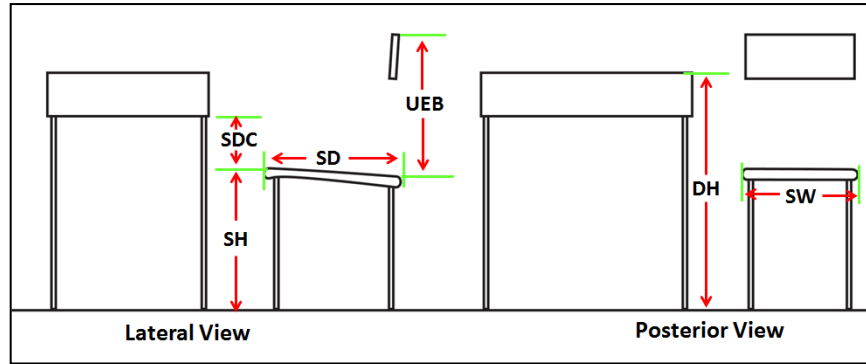


Figure 5.2. Furniture dimensions measured in the study.

5.2.4. Equations for Mismatch

In the literature, there is considerable variability in the equations that can be used to test the mismatch between anthropometric measures and furniture dimensions [25]. In this study, 6 furniture dimensions were evaluated, applying the methodology proposed by Castellucci et al. [25] (Table 5.2.). Some of the equations are two-way, where both the minimum and maximum limits were considered. In this case, three categories were defined: (i) "Match" level, when the furniture dimensions are between the minimum and maximum limits; (ii) "High mismatch" level, when the maximum limit of the equation is lower than the furniture dimension, indicating that the furniture dimension is higher than needed; and finally, (iii) "Low mismatch" level, when the minimum limit of the equation is higher than the furniture dimension – in this case, the furniture dimensions are lower than the recommended level.

Table 5.2. Proposed methodology for evaluating school furniture suitability

School furniture dimension	Mismatch equation	Observation
SH	$(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$	SC: (2 cm)
SD	$0.80BPL \leq SD \leq 0.95BPL$	
SW	$HW < SW$	
UEB	$SUH \geq UEB$	
SDC	$TT + 2 < SDC$	
DH	$(SH - (\sin X^\circ SD)) + EHS \leq DH \leq (SH - (\sin X^\circ SD)) + EHS * 0.8517 + SHS * 0.1483$	

Seat Height (SH), Seat Depth (SD), Seat Width (SW), Upper Edge of Backrest (UEB), Seat to Desk Clearance (SDC), Desk Height (DH), Popliteal Height (PH), Shoe Correction (SC), Buttock Popliteal Length (BPL), Hip Width (HW), Subscapular Height (SUH), Thigh Thickness (TT), Elbow Height Sitting (EHS), Shoulder Height Sitting (SHS).

5.2.5. Statistical analysis

All data were entered into Microsoft Office Excel 2007 and analysed using SPSS (v20.0). Independent t-tests (considering a 95% confidence interval) were performed to examine the differences in the anthropometric measurements between the different types of schools.

Additionally, categorical data were summarised using percentages and analysed using the chi-square test (cross table), with a 95% confidence interval. These were performed to test the association between the results of the mismatch levels (match/mismatch) and the three types of elementary school administrations (public, semi-public and private).

5.3. Results

5.3.1. Anthropometric Sample

The descriptive statistics of the eight anthropometric measures of the students from the different types of schools are presented in Table 5.3. Students from private schools had statistically larger dimensions than students from public schools, including S ($t=-2.62$; $p=0.009$), BPL ($t=-3.71$; $p=0.001$), SHS ($t=-2.76$; $p=0.006$), TT ($t=-4.23$; $p=0.001$) and SUH. ($t=-3.85$; $p=0.001$). This was also observed between private and semi-public schools for S ($t=-4.06$; $p=0.001$), for BPL ($t=-3.28$; $p=0.001$), SHS ($t=-2.54$; $p=0.01$), TT ($t=-4.78$; $p=0.001$), SUH ($t=-5.14$; $p=0.001$) and PH ($t=-2.51$; $p=0.01$). In the case of the comparison between public and semi-public schools, the difference was only statistically significant for PH ($t=3.41$; $p=0.01$).

Table 5.3. Anthropometric measures of the considered sample

Anthropometric measures (cm)	Public (n=815)		Semi-public (n=1,946)		Private (n=317)	
	Mean	S.D	Mean	S.D	Mean	S.D
Stature	148.9*	16.6	147.8 [□]	16.4	151.8* [□]	16.9
Shoulder height sitting	51.2*	6.4	51.4 [□]	6.6	52.4* [□]	6.4
Elbow height sitting	20.9	3.4	20.6	3.6	20.5	3.3
Thigh thickness	13.6*	2.4	13.6 [□]	2.3	14.3* [□]	2.0
Buttock-popliteal length	42.2*	5.1	42.5 [□]	5.1	43.5* [□]	5.2
Popliteal height	38.5°	4.3	37.9 ^{□°}	4.3	38.5 [□]	4.3
Subscapular height	38.4*	5.0	38.1 [□]	5.1	39.7* [□]	5.0
Hip width	32.3	4.6	32.6	4.7	32.4	4.6

* $p < 0.05$; [□] $p < 0.05$; ° $p < 0.05$;

5.3.2. School Furniture Dimensions

Before presenting and analyzing the school furniture of the different schools, it is important to mention that the sample included primary schools (1st to 8th grade, with ages of 6-12 years), secondary schools (9th to 12th grade, with ages of 13-18 years) and others with both levels. Due to this variability, some differences were observed regarding the number and type of desks and chairs that exist in each school. The different number of furniture types found at schools ranged from 1 to 4, depending on the school, and are represented in Table 5.4. Furniture type 1 is the name used for the smaller one and, on the opposite side, type 4 is used for the largest one. It is important to mention that all the evaluated school furniture was fixed, i.e. non-adjustable and built with plastic, wood and metal.

Chilean Decree 393 was published in 2010 and states that Chilean schools should have furniture according to the Chilean Standard 2566 [26]. This Standard recommends five levels of furniture dimensions to fit students from 1st to 12th grade (with ages of 6-18 years). Despite this, only school R bought, in 2011, the furniture dimensions indicated in the Standard. However, this school only bought the 3 highest levels indicated in the Standard, which are also the furniture sets with higher dimensions.

In Table 5.4., the schools other than school R have different sizes of school furniture and none of the schools have 5 levels. It is also important to mention that, in some cases, there are problems in the distribution of the furniture, such as the assignment of larger SH (A, C, D, I and Q), larger DH (A, C, L and Q) or lower SDC (A, C, I, N and P) to the youngest students.

Table 5.4. School furniture dimensions of the considered sample (cm)

Type of school	School	Type of furniture	Grade	SH	SW	SD	UEB	SDC	DH	SA
Public	A	1	1	39.8	35.5	32.6	32.0	19.8	67.7	0
		2	2 and 3	37.1	35.5	31.2	31.5	19.9	65.1	0
		3	4 to 8	40.5	36.5	36.5	34.8	16.5	75.6	0
	B	1	9 to 12	44.0	38.0	38.0	36.0	15.0	76.0	0
		1	1	35.0	36.0	36.0	36.0	12.0	65.0	0
	C	2	2, 5 and 6	44.0	36.0	32.0	39.0	16.0	74.0	0
		3	3 and 4	42.0	35.0	35.0	37.0	20.0	68.0	0
		4	7 and 8	42.0	36.0	36.0	36.0	18.0	75.0	0
	D	1	1 and 2	42.0	35.0	35.0	39.5	14.0	70.5	0
		2	3 to 8	41.5	35.5	35.0	39.5	17.0	75.5	0
	E	1	1 to 12	42.8	36.0	36.0	35.0	14.0	74.2	0
	F	1	1	37.0	35.0	33.0	34.7	9.3	63.5	5° BS
		2	2 to 8	43.5	36.0	36.0	36.0	13.5	75.0	5° BS
	G	1	1 to 4	38.0	35.0	33.0	34.7	13.7	69.0	0
		2	5 to 8	43.5	35.5	35.5	37.8	18.2	75.0	0
	H	1	1 to 8	42.7	36.2	36.2	36.0	17.8	75.7	0
Semi-public	I	1	1	40.5	35.0	33.5	33.5	8.5	64.0	5° BS
		2	2	44.0	34.5	34.5	39.0	10.0	69.5	5° BS
		3	3 and 4	43.0	34.0	34.0	38.5	19.0	75.0	5° BS
		4	5 to 12	44.5	34.0	34.0	34.5	13.0	75.5	5° BS
	J	1	1 and 2	37.0	35.0	32.0	33.0	11.0	63.0	0
		2	3 to 12	44.0	35.0	35.0	39.0	16.5	77.0	0
	K	1	1	38.0	39.5	39.5	32.0	12.0	66.0	0
		2	2 to 12	43.5	38.0	38.0	36.0	15.5	74.0	0
	L	1	1 and 2	43.5	35.5	35.5	39.0	10.0	70.5	5° BS
		2	3 to 8	43.5	33.5	33.5	39.0	10.5	68.5	5° BS
	M	1	1 and 2	37.5	35.0	33.0	36.0	10.5	65.5	0
		2	3 to 8	39.0	36.0	36.0	36.0	15.0	70.0	0
		3	9 to 12	42.0	36.0	36.0	36.0	17.0	76.0	0
	N	1	1 and 2	33.0	38.0	38.0	36.0	25.0	63.0	4° BS
		2	3 and 4	40.0	38.0	38.0	36.0	23.0	70.0	4° BS
		3	5 to 12	43.0	35.5	35.5	38.0	16.5	74.0	4° BS
	O	1	1 and 2	37.5	36.0	32.5	37.5	9.0	63.5	0
		2	3 to 8	42.0	35.5	35.5	40.0	12.5	70.5	0
		3	9 to 12	42.0	36.0	36.0	39.5	17.0	75.5	0
	P	1	1 and 2	36.0	34.5	34.5	37.0	14.5	65.5	0
		2	3 and 4	40.5	34.5	34.5	39.0	11.0	66.0	0
		3	5 to 12	40.5	34.5	34.5	39.5	19.0	71.0	0
Private	Q	1	1 and 2	37.8	35.3	32.7	34.0	12.2	68.3	0
		2	3 and 4	33.3	35.5	32.8	36.4	16.7	64.8	0
		3	5 to 10	42.5	35.8	36.0	34.5	18.5	73.5	0
		4	11 and 12	39.5	34.5	37.0	38.5	22.0	81.0	0
	R	1	1 and 2	38.0	38.0	33.0	32.0	18.0	63.0	4° BS
		2	3 to 6	41.0	40.0	39.0	37.0	20.0	68.0	4° BS
		3	7 to 12	45.0	40.0	39.0	37.0	21.0	73.0	4° BS

Seat Height (SH), Seat Depth (SD), Seat Width (SW), Upper Edge of Backrest (UEB), Seat to Desk Clearance (SDC), Desk Height (DH), Seat Angle (SA), Backward Slope (BS).

5.3.3. Mismatch Level

Figure 5.3. shows the level of mismatch determined by the one-way equations. Concerning SW, 17% of the students from public and private schools present narrow seats. In addition, higher values of mismatch (30%) were found in students of semi-public schools. Considering these results, it is possible to conclude that the level of “mismatch of SW” is associated with the “type of school” ($X^2 = 61.5$; $p < 0.001$).

The existence of a high Upper Edge of the Backrest (UEB), a high mismatch in this case, was verified for 31%, 45% and 22% of the students from public, semi-public and private schools, respectively (Figure 5.3.). Finally, the results presented in the current study shows that the level of “mismatch of UEB” does differ significantly according to the “type of school” ($X^2 = 87.1$; $p < 0.001$).

SDC dimension shows the greatest difference of mismatch between the “type of school”; moreover, there is a significant relationship between the level of “mismatch of SDC” and the “type of school” ($X^2 = 181.0$; $p < 0.001$).

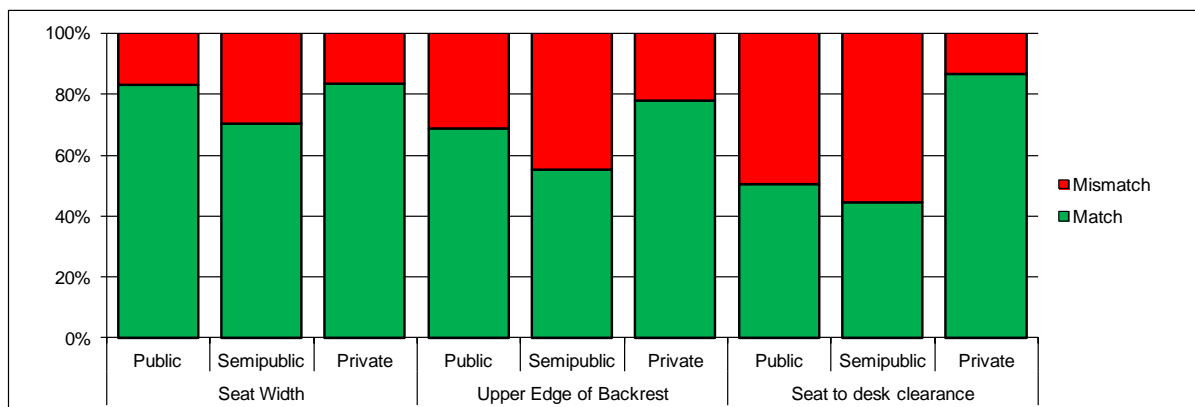


Figure 5.3. Mismatch percentages for one-way equation considering the type of school

Figure 5.4. shows that 68%, 72% and 59% of the students from public, semi-public and private schools, respectively, experienced a high mismatch in terms of their ability to rest their feet on the floor properly. On the other hand, only 1% and 4% of the students from semi-public and private schools, respectively, were shown to have lower SH than PH. Finally, as with the other dimensions, the results of the current study show that the level of “mismatch of SH” does differ according to the “type of school” ($X^2 = 16.4$; $p < 0.001$).

SD was greater than BPL (high mismatch) for 18% of the students from semi-public schools and for 16% of the students from public and private schools. Also, low mismatch was verified for 27%, 40% and 35% of the students from public, semi-public and private schools, respectively. Overall, there was a significant relationship between the level of “mismatch of SD” and the “type of school” ($X^2 = 56.3$; $p < 0.001$).

Finally, DH presents the highest levels of high mismatch (Figure 5.4.). Considering these results, it is also possible to conclude that the level of “mismatch of DH” is associated with the “type of school” ($X^2 = 14.8$; $p < 0.001$).

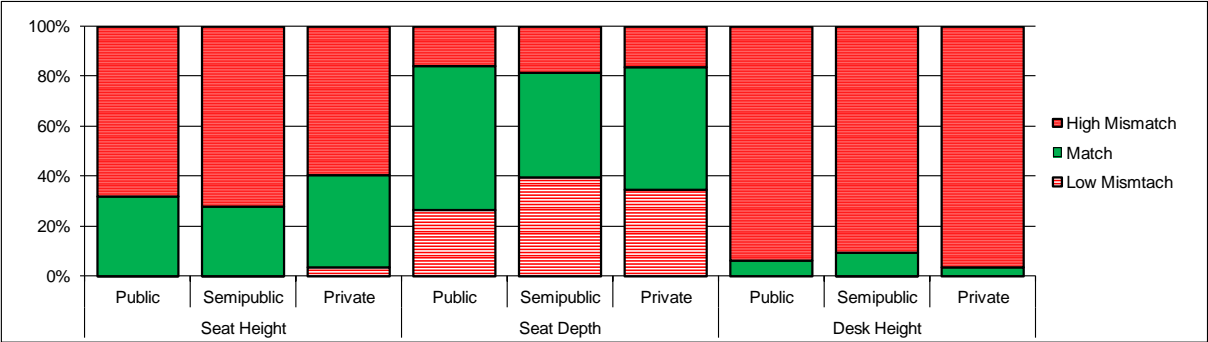


Figure 5.4. Mismatch percentages for two-way equation considering the type of school

To improve the analysis, Figure 5.5. shows the results of the cumulative fit or match. The cumulative fit is defined as the match that takes into account the cumulative values of the different furniture dimensions under analysis. If the cumulative fit is low, then the level of mismatch will be higher. The obtained results show very low values for cumulative fit, meaning a higher level of mismatch.

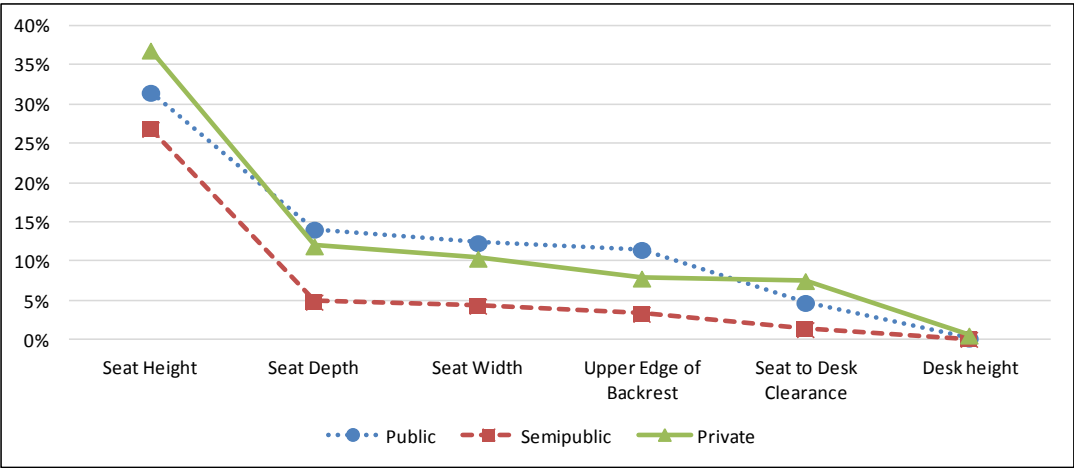


Figure 5.5. Cumulative fit considering the type of the school

5.4. Discussion

The results of this study are based on a representative sample of the students from the Valparaíso Region.

Seat Width presents the highest level of match. However there are some students that present narrow seats, which, according to some authors [27–31], may imply that they were not be able to relieve the pressure on the buttocks and were also not able to avoid discomfort and mobility restrictions.

The existence of a high Upper Edge of the Backrest (UEB), may result in the compression of the scapula and in a reduction in arm and trunk mobility, which can impair task performance and may initiate awkward postures in order to achieve tasked goals [29,32]. In the study of Castellucci et al. [20], the frequency of mismatch of UEB in Chilean schoolchildren, with ages of 12.5-14.5 years old, were lower, with values of 8%, 50% and 7% from public, semi-public and private schools, respectively. Similarly, Gouvali and Boudolos [33] found that 13.1% and 19.7% of Greek students, with ages of 6-18 years old, face the same problem.

SDC mismatch may restrain mobility because of the contact of the thighs with the desk [14,31] and because the students will not be able to push the chair under the table. This situation will force students to use a higher degree of trunk flexion to reach the table and do his/her work. This furniture dimension shows the greatest difference of mismatch between the “type of school” due the fact that 51% of the population from private schools use school furniture without a drawer (school R); this is the only type of school with this condition. One of the main problems associated with this mismatch is the presence of a drawer, used normally to store books and school materials during class time. Furthermore, some standards do not recommend the use of a drawer and suggested that the minimum table thickness that should be considered is either 7cm [26] or 7.5cm [34].

High SH may generate increased tissue pressure on the posterior surface of the knee [16,35,36]. On the other hand, a small number of students were shown to have lower SH than PH; this would increase the compression in the buttocks region [35], while also increasing the degree of lumbar flexion involved in sitting [37]. These mismatches are lower than those presented in a previous study by Castellucci et al. [20], with schoolchildren from the same region. They are also very similar to the one presented by Dianat et al. [38] with Iranian students (aged 15-18 years), whereby 65.8% and 50.1% of the high mismatches were for boys and girls, respectively.

Regarding SD, the results of the high mismatch condition from this study are lower than those presented by Dianat et al. [38] and Parcells et al. [14]. Using SD greater than BPL the students will not be able to use the backrest of the seat to support the lumbar spine without the seat pan compressing the popliteal surface [16]. To avoid this, students generally move their buttocks forward toward the front edge of the

seat [39]. This improper usage of the backrest causes kyphotic postures [40,41]. In the other hand, when the seat is too shallow (low mismatch) the students thighs would not be supported enough and would likely generate discomfort [37]. The results from the low mismatch condition are highest from those presented by Chung and Wong [13] and Dianat et al. [38].

DH presents the highest levels of high mismatch, where almost all the students would have to flex and abduct their arms, as well as elevate their shoulders. This may cause more muscle work load, discomfort and pain in the shoulder region [35]. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture [1]. The highest level of high mismatch observed in DH has already been reported in almost all of the studies that have been conducted in this area worldwide [13,14,17,20,42–43]. However, only 1% of the students from semi-public schools presented low mismatch and are forced to bend their torso forward, with their body weight being supported mainly by their arms. This may result in a kyphotic spinal posture with rounded shoulders.

It is important to consider that the mismatch results from the 6 furniture dimensions are significantly associated with the “type of school”. Furthermore, the private schools presented the highest level of match in 4 out of 6 furniture dimensions (SH, SW, UEB and SDC). It could be assumed that these results are explained by private schools having more resources and therefore more adequate furniture. However, these results should be interpreted with caution since, as mentioned before, one of the private schools bought the furniture according to the Chilean Standard (School R), but without any previous ergonomic concerns about their dimensions. Furthermore, not many differences can be seen in the level of cumulative fit between the different “type of school” (Figure 5.5.). The higher levels of mismatch will likely have a negative effect on posture, comfort and performance in the students from the different types of schools.

As previously mentioned, a prior study was carried out in the same region with a smaller sample and considered only one school grade [20]. Comparing the current results with those presented by Castellucci et al. [20], we can see that for the current sample there were higher levels of mismatch regarding SDC, SW, UEB and SD. On the other hand, SH and DH present a lower level of mismatch in the current study. The highest level of mismatch presented can be associated with the fact that the furniture acquisition by schools is made without considering any ergonomic criteria and, most importantly, teachers and school authorities are not aware of this.

One possible solution to this problem is the need to involve the entire school community in this analysis and raise their awareness about the existence of Chilean Standard 2566 and of the implications of the identified mismatch in the students’ current and future health.

5.5. Limitations

Despite the fact that this study included a very large sample of participants and an extensive database, it should be acknowledged that the conclusions are somewhat limited by the fact that these are based on the analysis of a specific region of Chile. Also, it is important to note that it is likely that the formulation of the applied equation may include some problems and thus needs to be evaluated in detail, both in the field and in the laboratory [23].

5.6. Conclusions

This paper describes the results obtained from a large sample of students from the Valparaíso region of Chile. These results show that there is a difference between student anthropometric measures (e.g., Stature,) when considering the different school types, particularly between the private schools and the other schools, as well as the socio-economic status of the students, particularly between the high and the other socio-economical levels.

Concerning school furniture, some differences were observed regarding the number and type of desks and chairs that exist in each school. Furthermore, high levels of mismatch in almost all the furniture dimensions analysed were noted, with the higher levels of mismatch occurring in seat height, desk height and seat-to-desk clearance. Also, the simultaneous analysis of all the considered dimensions shows that there is a high level of cumulative mismatch overall, regardless of school type.

Even if the lowest level of mismatch were presented by the private schools in almost all the furniture dimensions, the cumulative fit shows similar results between the types of schools. Furthermore, this situation can be associated with the fact that the furniture acquisition by schools is made without considering any ergonomic criteria.

References

- [1] Zacharkow D. Posture: sitting, standing, chair design and exercise. Springfield: Charles C. Thomas.; 1987.
- [2] Hira DS. An ergonomic appraisal of educational desks. *Ergonomics*. 1980; 23(3): 213.
- [3] Kumar S, Mital A. Margin of safety for the human back: a probable consensus based on published studies. *Ergonomics*. 1992;35(7,8):769–81.

- [4] Gonçalves MA, Arezes PM. Postural assessment of school children : an input for the design of furniture. *Work*. 2012; 41: 876.
- [5] Linton SJ, Hellsing a L, Halme T, Akerstedt K. The effects of ergonomically designed school furniture on pupils' attitudes, symptoms and behaviour. *Appl Ergon*. 1994; 25 (5): 299.
- [6] Saarni L, Nygård C-H, Rimpelä A, Nummi T, Kaukiainen A. The working postures among schoolchildren—a controlled intervention study on the effects of newly designed workstations. *Journal of School Health*. 2007; 77(5): 240.
- [7] Oxford HW. Anthropometric data for educational chairs. *Ergonomics*. 1969;12 (2): 140.
- [8] Lueder R, Berg Rice V. *Ergonomics for children*. London: Taylor & Francis; 2008.
- [9] Savanur CS, Altekar CR, De A. Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics*. 2007; 50: 1612.
- [10] Yeats B. Factors that may influence the postural health of schoolchildren (K-12). *Work*. 1997; 9 (1): 45.
- [11] Feathers D, Pavlovic-Veselinovic S, Hedge A. Measures of fit and discomfort for elementary school children in Serbia. *Work*. 2013; 44 (1): S73.
- [12] Agha SR. School furniture match to students' anthropometry in the Gaza Strip. *Ergonomics*. 2010; 53 (5): 344
- [13] Chung JWY, Wong TKS. Anthropometric evaluation for primary school furniture design. *Ergonomics*. 2007; 50 (3): 323. 1
- [14] Parcels C, Stommel M, Hubbard RP. Mismatch of classroom furniture and student body dimensions: empirical findings and health implications. *J Adolesc Health*. 1999; 24 (4): 265.
- [15] Batistaõ MV, Sentanin AC, Moriguchi CS, Hansson G-Å, Coury HJCG, de Oliveira Sato T. Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs. *Work*. 2012; 41 (1): 4817.
- [16] Milanese S, Grimmer K. School furniture and the user population: an anthropometric perspective. *Ergonomics*. 2004; 47: 416
- [17] Ramadan MZ. Does Saudi school furniture meet ergonomics requirements? *Work*. 2011; 38 (2): 93.
- [18] Sents BE, Marks HE. Changes in preschool children's IQ scores as a function of positioning. *Am J Occup Ther*. 1989; (43): 685
- [19] Smith-Zuzovsky N, Exner C. The effect of seated positioning quality on typical 6- and 7-year-old children's object manipulation skills. *Am J Occup Ther*. 2004; 58 (4): 380.
- [20] Castellucci HI, Arezes PM, Viviani CA. Mismatch between classroom furniture and anthropometric measures in Chilean schools. *Appl Ergon*. 2010; 41 (4): 563.

- [21] Muzzo B. Crecimiento normal y patológico del niño y del adolescente. *Rev Chil Nutr.* 2003; 30 (2): 92.
- [22] González P, Mizala A, Romaguera P. Vouchers, Inequalities and the Chilean Experience. Santiago de Chile: CEA.; 2004.
- [23] Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* 3rd Edition. Upper Saddle River: Pearson/Prentice Hall; 2008.
- [24] ISO. ISO 7250: Basic human body measurements for technological design. International Organization for Standardization, Geneva, Switzerland; 1996
- [25] Castellucci HI, Arezes PM, Molenbroek JFM. Applying different equations to evaluate the level of mismatch between students and school furniture. *Appl Ergon*; 45 (4): 1123.
- [26] INN (Instituto Nacional de Normalización Chile). Norma Chilena 2566. Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales. Santiago de Chile: INN; 2002.
- [27] Evans WA, Courtney AJ, Fok KF. The design of school furniture for Hong Kong school children: an anthropometric case study. *Appl Ergon.* 1988; 19: 122.
- [28] Occhipinti E, Colombini D, Molteni G, Grieco A. Criteria for the ergonomic evaluation of work chairs. *Le Med del Lav.* 1993; 84 (4): 274..
- [29] Orborne DJ. *Ergonomics at Work: Human factors in design and development.* 3rd Edition. John Wiley & Sons, Chichester; 1996.
- [30] Oyewole SA, Haight JM, Freivalds A. The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *Int J Ind Ergon.* 2010; 40 (4): 437.
- [31] Sanders MS, McCormick . EJ. *Applied anthropometry, work-space design and seating . Human factors in engineering and design.* 7th Edition. Singapore: McGraw-Hill; 1993.
- [32] García-Acosta G, Lange-Morales K. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric criteria. *Ergonomics.* 2007; 50: 1626.
- [33] Gouvali MK, Boudolos K. Match between school furniture dimensions and children's anthropometry. *Appl Ergon.* 2006;37:765–73.
- [34] BSI (British Standard Institution). BS EN 1729-1: 2006 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions. UK: BSI; 2006.
- [35] García-Molina C, Moraga Tortosa, L. R, Verde V. *Guía de Recomendaciones para el Diseño de mobiliario ergonómico.* Valencia: Instituto Biomecánico de Valencia; 1992.
- [36] UNESCO. *Guía de recomendaciones para el diseño del mobiliario escolar .* Chile: Ministerio de Educación and UNESCO; 2001..
- [37] Pheasant S. *Bodyspace.* 2nd Edition. London: Taylor & Francis; 2003.

- [38] Dianat I, Karimi MA, Asl Hashemi A, Bahrampour S. Classroom furniture and anthropometric characteristics of Iranian high school students: proposed dimensions based on anthropometric data. *Appl Ergon.* 2013; 44 (1):101.
- [39] Panagiotopoulou G, Christoulas K, Papanickolaou A, Mandroukas K. Classroom furniture dimensions and anthropometric measures in primary school. *Appl Ergon.* 2004; 35: 121.
- [40] Khalil TM, Abdel-Moty EM, Rosomoff RS, Rosomoff HL. *Ergonomics in back pain: A guide to prevention and rehabilitation.* New York: Van Nostrand Reinhold; 1993.
- [41] Pheasant S. *Ergonomics, work and health.* Hong Kong: Macmillan; 1991.
- [42] Brewer JM, Davis KG, Dunning KK, Succop PA. Does ergonomic mismatch at school impact pain in school children ? *Work.* 2009; 34: 455.
- [43] Cotton LM, Connell DGO, Palmer PP, Rutland MD. Mismatch of school desks and chairs by ethnicity and grade level in middle school. *Work.* 2002; 18: 269.

CHAPTER 6| The Effect of Secular Trends in the Classroom Furniture Mismatch: Support for Continuous Update of School Furniture Standards

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In order to create safer schools, the Chilean authorities published a Standard regarding school furniture dimensions. The aims of this study are twofold: to verify the existence of positive secular trend within the Chilean student population and to evaluate the potential mismatch between the anthropometric characteristics and the school furniture dimensions defined by the mentioned standard. The sample consists of 3,078 subjects. Eight anthropometric measures were gathered, together with six furniture dimensions from the mentioned standard. There is an average increase for some dimensions within the Chilean student population over the past two decades. Accordingly, almost 18% of the students will find the seat height to be too high. Seat depth will be considered as being too shallow for 42.8% of the students. It can be concluded that the Chilean student population has increased in stature, which supports the need to revise and update the data from the mentioned Standard.

Keywords: School; furniture; Standard, Secular trend, Mismatch

6.1. Introduction

Children may spend most of their waking hours at school, most of them in the sitting position (Troussier et al. 1999). Being seated for a long period of time on school furniture has been associated with reported musculoskeletal discomfort and pain (Fallon and Jameson 1996). Moreover, poor sitting habits acquired during childhood are very difficult to change later in adolescence and/or adulthood (Yeats 1997). Also, postural and musculoskeletal dysfunctions can increase during high growth stages, such as puberty (Savanur et al. 2007).

This situation has provoked an increased concern about school classrooms, particularly regarding the study and design of school furniture suitable to the needs of the students, with furniture that has the

appropriate dimensions according to the students' anthropometric characteristics. This concern is made clear by the large number of studies published worldwide; these studies show a clear mismatch between anthropometric characteristics and the dimensions of the furniture under study (Brewer et al. 2009, Castellucci et al. 2010, Cotton et al. 2002, Dianat et al. 2013, Feathers et al. 2013, Panagiotopoulou et al. 2004, Ramadan 2011, Van Niekerk et al. 2013). Furthermore, an important milestone in this increasing concern is the publication of Chilean Standard 2566 (INN 2002), which determines the dimensions and characteristics of different types of school furniture for the whole Chilean population.

Despite this, in a study carried out with Chilean students (Castellucci et al. 2010), the authors conclude that classroom furniture was, in almost all the analysed cases and subjects, not adequate for the student population. In this study, seat height (SH) and desk height (DH) were the furniture dimensions that were identified as presenting the highest level of mismatch.

After the completion of the above mentioned study, during 2010, Chilean Decree 393 was published. This Decree states that schools should have furniture according to the current standards published by the National Institute of Standardization. The main aim of this decree was also to generate safer schools as well as counteract the lack of knowledge and applicability of Chilean Standard 2566.

These actions that have occurred in Chile are very important steps when considering the words of Lueder and Berg Rice (2008): "There is a lack of standardization for the design of classroom furniture for educational settings in many countries, with the exception of Europe, where the development of school furniture standards has been most actively pursued. There is a European Standard that gives very general requirements and an Austrian Standard. Currently, there is also discussion of a European draft educational furniture Standard prEN 1729. Given the anthropometric diversity of many countries, the development of an International Standard could be of benefit".

Another issue in these kind of studies is the well-known positive secular trend or growth observed in some populations, which has been defined as an increase in mean body stature (S) or height among persons of the same age of successive generations. Whether this increase is equally distributed over the whole body or only in certain segments is not yet completely known (Steenbekkers 1993). This positive secular trend has been observed in different countries, with an average growth between 0.7 cm and 4 cm per decade (Gutiérrez and Apud 1992, Fredriks et al. 2000). It is generally assumed that this secular trend is elicited by a change in environmental conditions, in particular by removing factors that had blocked full expression of the biologic potential, such as infectious diseases, inadequate nutrition, poverty and suffering (Tanner 1992). The growth of a population can therefore be assumed to be a "mirror of conditions in society" (Tanner 1986). A positive secular trend is assumed to reflect changes in living standards and dietary habits (Hauspie et al. 1996). In the scope of this study, a positive secular trend is a very important factor

to consider because the anthropometric data used in Chilean Standard 2566 was obtained in 1990 (Gutiérrez and Apud 1992, UNESCO 2001), which could indicate that the standard data may be out of date. Also, secular trend causes temporal changes in the accommodation levels afforded by long-lifetime products. Utilising forecasts of trends and their impacts on target population anthropometry can help make designs suitable for future populations (Nadadur and Parkinson 2013).

Considering the previously stated information, the research question considered for this study was: Is there a need to adapt the Chilean Standard 2566 due to the current positive secular growth observed in the Chilean student population? Furthermore the aims of this study are twofold: (i) analyse whether if the Chilean student population has registered secular growth between 1990 and 2012 and (ii) whether the Chilean Standard 2566 data are still valid to fit, or match, the current student anthropometric characteristics.

6.2. Methods

6.2.1. Participants

It is important to mention that, in Chile, growth is influenced by socio-economic aspects, where it has been observed that children from higher socio-economic levels are taller than those of lower and medium socio-economic levels (Castellucci et al. 2010, Muzzo 2003). This differentiated growth calls for the use of a cluster design regarding the three types of elementary school administrations in Chile (public, semi-public and private), as well as the financial situation of the corresponding students. As the three different types of schools represent different situations regarding the involved educational costs, there is a close association between the type of school and the economic level of the students. The estimated student population of basic and secondary schools in the Valparaíso region during 2010 was 243,490 students. Considering a 50% prevalence of school furniture mismatch ($p=0.5$ to obtain the largest sample), with 3% accuracy, 95% confidence intervals and 15% of loss, the theoretical sample size is 1,251 students. However, based on the Chilean school education system, every school has 12 grades, with students ranging from the age of 5 to 19 years. In order to cover all of them, it was decided to use a random sample of at least 20 students per grade, keeping the proportionality of each cluster (Table 6.1.). The real sample, gathered during 2012, involved a group of 3,078 students (1,397 female and 1,681 male) from 18 schools, with ages ranging from 5 to 19 years (11.7 ± 3.5).

Table 6.1. Study sample characterisation

Grade	Estimated sample			Real sample		
	Public	Semi-public	Private	Public	Semi-public	Private
1	55	135	20	55	143	25
2	55	135	20	55	171	21
3	55	135	20	69	176	27
4	55	135	20	75	190	21
5	55	135	20	82	170	36
6	55	135	20	109	158	33
7	55	135	20	70	182	28
8	55	135	20	61	145	28
9	55	135	20	67	172	28
10	55	135	20	62	147	23
11	55	135	20	55	132	26
12	55	135	20	55	160	21
Total	660	1620	240	815	1946	317
Total %	26.2	64.6	9.2	26.5	63.2	10.3

6.2.2. Procedure for data collection

6.2.2.1. Training Evaluations Teams

The measurement process was carried out by two survey teams, composed of four people in each team: a measurer, a recorder, an organiser, and another person to support the measurer. To avoid fatigue and monotony, the team members were able to switch from measurer to organiser and from recorder to measurer support.

Before starting the survey, the measurement teams underwent a training session of 2 weeks, including a theoretical approach about anthropometrics as well as practical instructions. They spent considerable time practicing the measurements to achieve high consistency between measurers. At the end of the training sessions, both inter- and intra-measurer reliability were assessed by paired sample t-tests (with a 95% confidence interval).

6.2.2.2. Anthropometric Measures

The anthropometric measurements were collected following exactly the same measurement protocol that was used to obtain the measures from the 1990 sample, as described in Gutiérrez and Apud (1992). The measurements were collected from the right side of the subjects while they were sitting in an erect position on a height-adjustable chair with a horizontal seat surface, their legs flexed at a 90° angle and with their feet flat on an adjustable footrest. During the measurement process, the subjects were without shoes and they were wearing shorts and t-shirts.

All measurements were taken with a Harpenden standard anthropometer (Holtain Ltd., Crymch, UK), exception made to subjects' S, which was measured with an estadiometer.

The anthropometric measures considered and collected during this study are presented in Table 6.2.

Table 6.2. Anthropometric measurements considered in the study

Anthropometric measurements	Definition
SHS	Vertical distance from subject's seated surface to the acromion
EHS	Taken with a 90° angle elbow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface
TT	The vertical distance from the highest uncompressed point of thigh to the subject's seated surface
BPL	Taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface
PH	Measured with 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface)
SUH	The vertical distance from the lowest point (inferior angle) of the scapula to the subject's seated surface
HW	The horizontal distance measured in the widest point of the hip in the sitting position
S	Determined as the vertical distance between the floor and the top of the head, and measured with the subject erect and looking straight ahead (Frankfort plane)

6.2.2.3. Furniture Dimensions

Table 6.3. shows the five levels of furniture dimensions indicated in Chilean Standard 2566 (INN 2002). It is important to mention that Chilean Standard 2566, like most of the standards worldwide, indicates that the S of the school children should be used to select the furniture, assuming that all the other anthropometric characteristics will also be appropriate. Regarding the seat angle, the standard considered a 4° backward slope or negative seat angle.

Table 6.3. School furniture dimensions from the Chilean Standard 2566 (cm)

School furniture dimension (cm)	School furniture levels				
	1	2	3	4	5
SH	30	34	38	41	45
SD	27	29	33	39	39
SW	34	34	38	40	40
UEB	27	29	32	37	37
SDC	14	16	18	20	21
DH	51	57	63	68	73
Reference Stature	110-123	123-137	137-151	151-168	168-184

6.2.3. Mismatch equations and health implications

After assigning the level of school furniture (using S) to each of the students in the sample, the different mismatch equations were applied. Some of the equations are two-way, i.e. where both the minimum and maximum limits were considered. For these cases, three categories were defined: (1) "Match" level – when the furniture dimension is between the limits (2) "High Mismatch" level – when the maximum limit of the equation is lower than the furniture dimension, indicating that the furniture dimension is higher than needed and (3) "Low Mismatch" level – when the minimum limit of the equation is higher than the furniture dimension (in this case, the furniture dimension is lower than the recommended level).

6.2.3.1. Seat height

Most of the researchers have concluded that popliteal height (PH) should be higher than SH (Mokdad and Al-Ansari 2009, Parcels et al. 1999, Molenbroek and Ramaekers 1996), otherwise most students will be unable to rest their feet on the floor properly, thus causing compression of vascular and neural structures going along the popliteal space (Milanese and Grimmer 2004). However, if SH is significantly lower than PH, more than 4 cm (UNESCO, 2001), this will increase the compression in the buttock region (García-Molina et al. 1992). The equation used in this study is based on the angles of the knee (Eq.1), considering that SH needs to be lower than PH so that the lower leg forms a 5-30° angle relative to the vertical and that the angle range will permit the student to sit in a chair high enough so that both feet are placed entirely on the floor. However, the seat should be low enough to avoid an extension of more than 30° relative to the vertical in the knee joint. This is important since with more extension, the feet will not be placed flat on the floor or the thighs would not be supported enough, generating discomfort. In this case, the mismatch equation was

$$(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ \quad (\text{Eq. 1})$$

SC is shoe correction 2 cm of shoe sole was considered.

6.2.3.2. Seat depth

Buttock popliteal length (BPL) is the anthropometric measure used to designate the size of the seat depth (SD) (Helander 1997, Khalil et al. 1993, Orborne 1996). If the SD is greater than the BPL, the student will not be able to use the backrest of the seat to support the lumbar spine without compression of the popliteal surface (Milanese and Grimmer 2004). To avoid this it is likely that the student will generally move their buttocks forward toward the edge of the seat, as suggested by Panagiotopoulou et al. (2004). This improper usage of the backrest causes kyphotic posture (Khalil et al. 1993, Pheasant 1991). However, if the SD is considerably shorter than the BPL of the student, then the thigh will not be fully

supported and extra pressure will be distributed on the back of the thighs, causing discomfort (Pheasant 2003). The applied equation is

$$0.80BPL \leq SD \leq 0.95BPL \quad (\text{Eq. 2})$$

6.2.3.3. Seat width

To avoid discomfort and mobility restrictions, the seat width (SW) should be higher than hip width (HW) (Evans et al. 1988, Helander 1997, Orborne 1996, Oyewole et al. 2010). Moreover, Gouvali and Boudolos (2006) suggest that the SW should be at least 10%, but not more than 30%, larger than the HW in order to provide proper seating while making economic use of space. In this case, the corresponding mismatch equations are

$$HW < SW \quad (\text{Eq. 3})$$

6.2.3.4. Upper edge of backrest

When students use a chair with Upper edge of backrest (UEB) higher than subscapular height (SUH), this will result in compression of the scapula and a reduction in arm and trunk mobility (García-Acosta and Lange-Morales 2007, Orborne 1996) which can complicate task performance and cause awkward postures in order to achieve task goals. As a result, the used equation is

$$SUH \geq UEB \quad (\text{Eq. 4})$$

6.2.3.5. Seat to desk clearance

Seat to desk clearance (SDC) is considered appropriate when it is higher than thigh thickness (TT). Also, Parcels et al. (1999) propose that the desk clearance should be 2 cm higher than knee height, considering these situations, the applied equation is:

$$TT + 2 < SDC \quad (\text{Eq. 5})$$

6.2.3.6. Desk height

Elbow height sitting (EHS) is the major criterion for DH (García-Acosta and Lange-Morales 2007, Milanese and Grimmer 2004, Molenbroek et al. 2003). It is also accepted that EHS can be considered as the minimum height of DH in order to provide a significant reduction in spinal loading (Occhipinti et al. 1985). However, the maximum DH, as outlined by Chaffin and Anderson's principles (1991), depend on shoulder flexion and shoulder abduction angles of 25° and 20°, respectively. Also, the backward slope of the chairs is considered in the following equation, since the elbow is aligned with the back of the seat and is lower than the front edge. The applied equation is:

$$[SH - (\sin X^\circ SD)] + EHS \leq DH \leq [SH - (\sin X^\circ SD)] + EHS \cdot 0.8517 + SHS \cdot 0.1483 \quad (\text{Eq. 6})$$

It is also important to consider the cumulative fit, which is defined as the mismatch, which takes into account the cumulative values of the different furniture dimensions. This can be considered as a very important indicator of the furniture fit, or match, since it shows how many students are actually matched to the dimensions of the school furniture defined by the standard. If the cumulative fit is low, then the level of mismatch will be higher, thus having a negative effect on posture, comfort and performance. The order to apply the cumulative fit is the same as presented earlier.

6.2.4. Data Analysis

Statistical analyses were performed using SPSS (version 20.0.1; SPSS Inc., Chicago, IL). An independent t-test (with a 95% confidence interval) was performed to examine the differences in measurements between the different types of schools. Also, this test was performed to examine the differences in measurements between the samples from 2012 and 1990.

6.2.5. Ethics

The study was approved by the Committee of Ethics at the School of Medicine from the Universidad de Valparaíso. Permission to conduct this research was obtained from Regional Ministerial Secretary of Education and the headmaster of each of the schools considered. Also, written consent was obtained from parents and students before starting the measurement procedures.

6.3. Results

6.3.1. Generalities

The descriptive statistics of the eight anthropometric measures of the students of the different type of schools are presented in Table 6.4. The obtained results show that the students from private schools have higher dimensions than those from public school, and that applies for S ($t=-2.62$; $p=0.009$), BPL ($t=-3.71$; $p=0.001$), shoulder height sitting (SHS) ($t=-2.76$; $p=0.006$), TT ($t=-4.23$; $p=0.001$) and SUH ($t=-3.85$; $p=0.001$). This situation is also observed between private and semi-public schools for S ($t=4.06$; $p=0.001$), BPL ($t=3.28$; $p=0.001$), SHS ($t=2.54$; $p=0.01$), TT ($t=4.78$; $p=0.001$), SUH ($t=5.14$; $p=0.001$) and PH ($t=2.51$; $p=0.01$). In the case of public and semi-public schools, the difference is only statistically significant for PH ($t=3.41$; $p=0.01$).

Table 6.4. Anthropometric data from the study sample

Anthropometric measures	Public		Semi-public		Private	
	Mean	S.D	Mean	S.D	Mean	S.D
SHS (cm)	51.2	6.4	51.4	6.6	52.4	6.4
EHS (cm)	20.9	3.4	20.6	3.6	20.5	3.3
TT (cm)	13.6	2.4	13.6	2.3	14.3	2
BPL (cm)	42.2	5.1	42.5	5.1	43.5	5.2
PH (cm)	38.5	4.3	37.9	4.3	38.5	4.3
SUH (cm)	38.4	5	38.1	5.1	39.7	5
HW (cm)	32.3	4.6	32.6	4.7	32.4	4.6
S (cm)	148.9	16.6	147.8	16.4	151.8	16.9
Weight (Kg)	49.2	17.5	48.3	16.3	49.2	15.7
Body mass index	21.4	4.3	21.4	4.1	20.7	3.3

6.3.2. Differences between 2012 and 1990 samples

Before analysing the current measures and comparing them to those of 1990, it is important to emphasise that although both samples were distributed according to the socio-economic level of the students, they were taken from two different regions in Chile. The 1990 sample consisted of a distribution of 34%, 46% and 20% for the low, medium and high socio-economic levels, respectively (Gutiérrez and Apud 1992). The current study sample, as mentioned earlier (Table 6.1.), was made up of 26.5%, 63.2% and 10.3% of the low, medium and high socio-economic levels, respectively. The differences in the percentage of the socio-economic levels between the two samples, as it was mentioned previously, may represent an additional source of anthropometric variability that needs to be acknowledged. It is also important to mention that in both samples age was defined by considering the date of birth to the next date of birth, for example, if the student has not completed his/her 8th year, his/her age was classified as being 7 years old.

The results from Figure 6.1. suggest the existence of a secular trend regarding the S of the students. The magnitude of the increased S over the studied years is higher for females and males in the age range of 6-10 years. However, at the age of 13, the difference in the S of females starts to decrease until 16 years of age. The S of males was found to have increased at virtually all ages; the exceptions were no change for 12 and 17 years of age and a decrease for the 18 year old students.

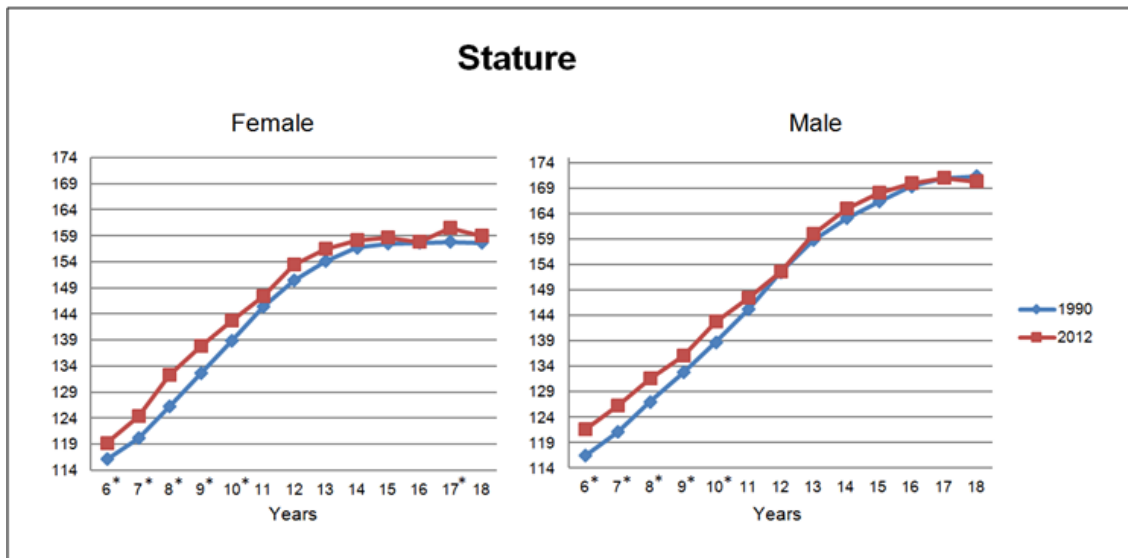


Figure 6.1. Differences in S between the samples from the 2012 and 1990 studies (*significant difference)

PH not only is considered a very important anthropometric measure for the design and evaluation of school furniture, but some authors (Evans et al. 1988, Hibar and Watanabe 1994, Molenbroek et al. 2003) also suggest that the furniture selection can be done more efficiently by using this measure. PH has increased at virtually all ages for males and females, despite that the largest increases being found in females (Figure 6.2.).

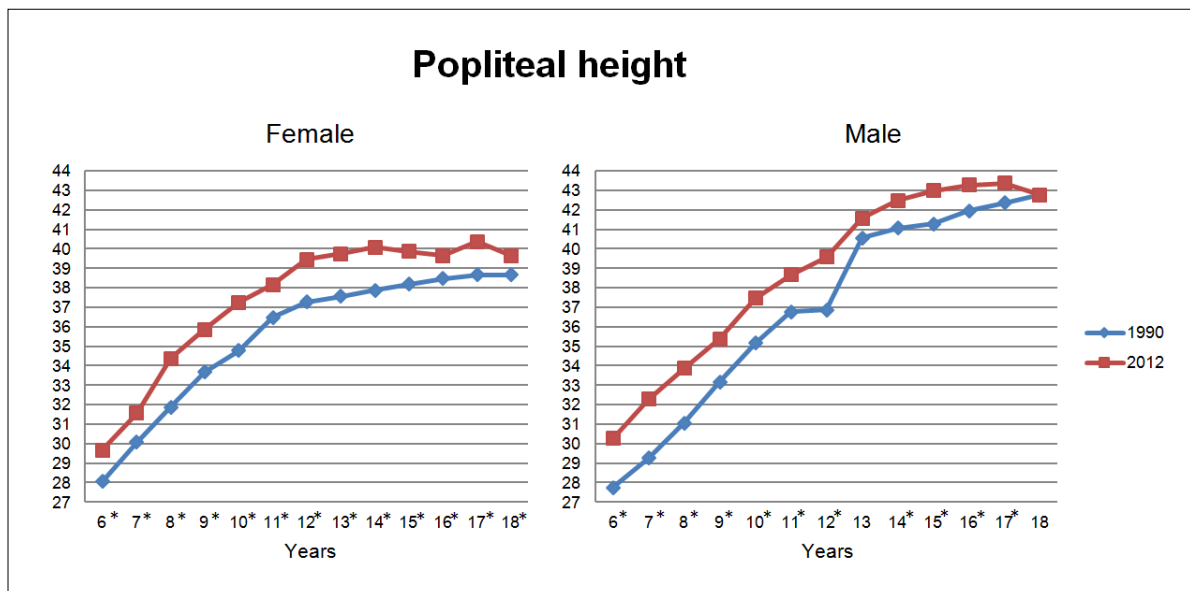


Figure 6.2. Differences in PH between the samples from the 2012 and 1990 studies (*significant difference)

The 2012 sample means values for BPL are higher than the values obtained in the 1990 sample throughout the entire age range (Figure 6.3.). The differences between the two samples range from 0 cm to 3 cm. The same trend prevails in HW (Figure 6.4.).

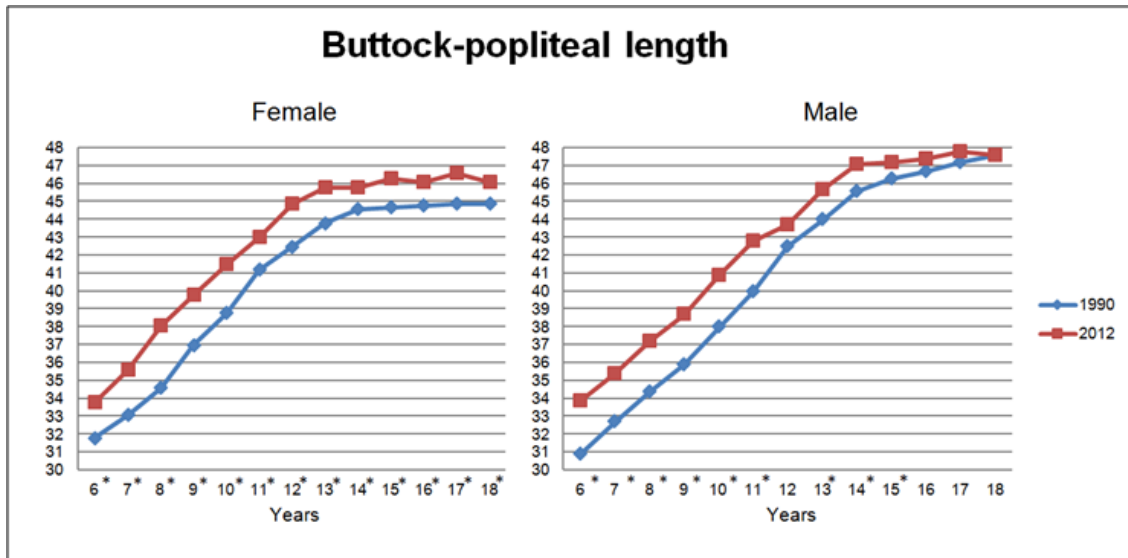


Figure 6.3. Differences in BPL between 2012 and 1990 studies (*significant difference)

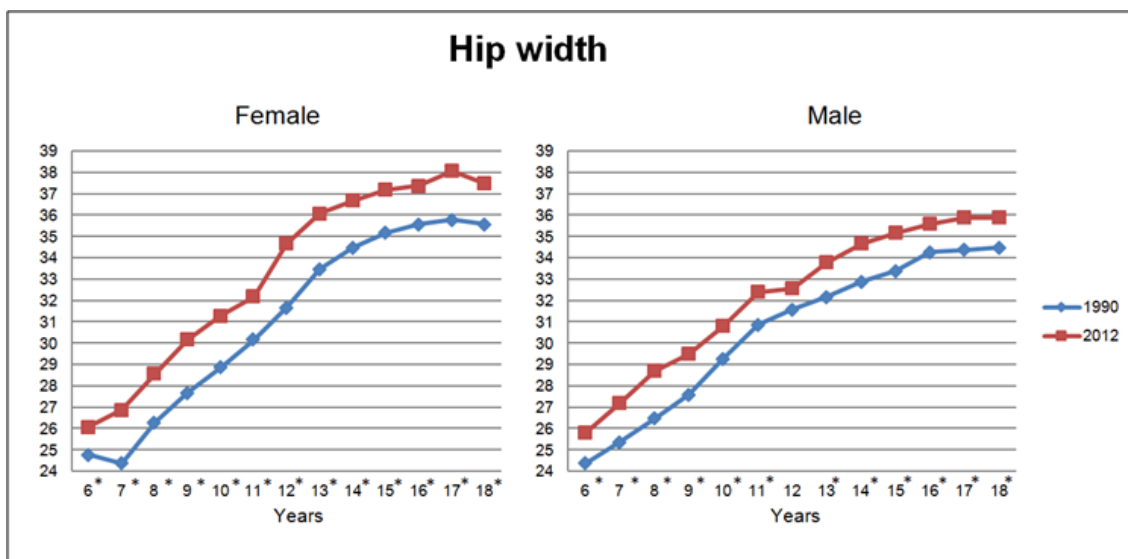


Figure 6.4. Differences in HW between the samples from the 2012 and 1990 studies (*significant difference)

6.3.3. Mismatch level of the Chilean Standard

Before the presentation of the results, it is important to mention that by using S, 12 students are considered to be out of the reference S range (Table 6.3.) 3 below 110 cm and 9 above 184 cm.

The analysis of the mismatch level of the Chilean Standard starts with the two-way equation (Table 6.5.), specifically with SH, since it is considered as the starting point and the most important variable for the design and evaluation of the classroom furniture. Most of the students (82%) will use school furniture with appropriate SH. However, SH will be higher for 16.9% of the students, who will be unable to rest their feet on the floor properly, thus generating increased tissue pressure on the posterior surface of the knee (García-Molina et al. 1992, Milanese and Grimmer 2004). Only 1.1% of the students will find the SH to be too low, increasing the compression in the buttock region (García-Molina et al. 1992), while also increasing the degree of lumbar flexion involved in sitting (Pheasant 2003).

Table 6.5. Percentages of students by match/mismatch level for the two-way equations.

	SH (%)	SD (%)	DH (%)
High mismatch	16.9	0.4	82.2
Match	82.0	56.8	17.1
Low mismatch	1.1	42.8	0.8

A large number of students will find the seat too shallow (Table 6.5.), for which their thighs would not be supported enough and would generate discomfort (Pheasant 2003).

Finally, Table 6.5. shows that 82.2% of the students will use a high desk. This (high) mismatch will cause the students to flex and abduct their upper arms as well as raise their shoulders which, in the opinion of García-Molina et al. (1992), may result in more muscle work load, discomfort and pain in the shoulder region. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture.

Table 6.6. illustrates the results of the application of one-way equations. In this situation, a very high level of match is observed in three furniture dimensions, none of them exceeding 10% mismatch. Narrower seats will exist only for 7% of students. Accordingly, in this mismatch situation, and according to Helander (1997) and Orborne (1996) the school children will not be able to dissipate the pressure at the buttock, which will also cause discomfort and mobility restrictions. The same percentages will be also observed in SDC, which do not allow the students to push the chair under the table and do not allow enough space for leg movement. UEB presents the lowest level of mismatch (2%) and this result was not observed in any of the previously published studies (Agha 2010, Castellucci et al. 2010, Dianat et al. 2013, Gouvali and Boudolos 2006).

Finally, applying all the formulas, only 7% of students will fit the furniture size assigned using the Chilean Standard (Figure 6.5.).

Table 6.6. Percentages of students by match/mismatch level for the one-way equations.

	SW (%)	UEB (%)	SDC (%)
Mismatch	7	2	7
Match	93	98	93

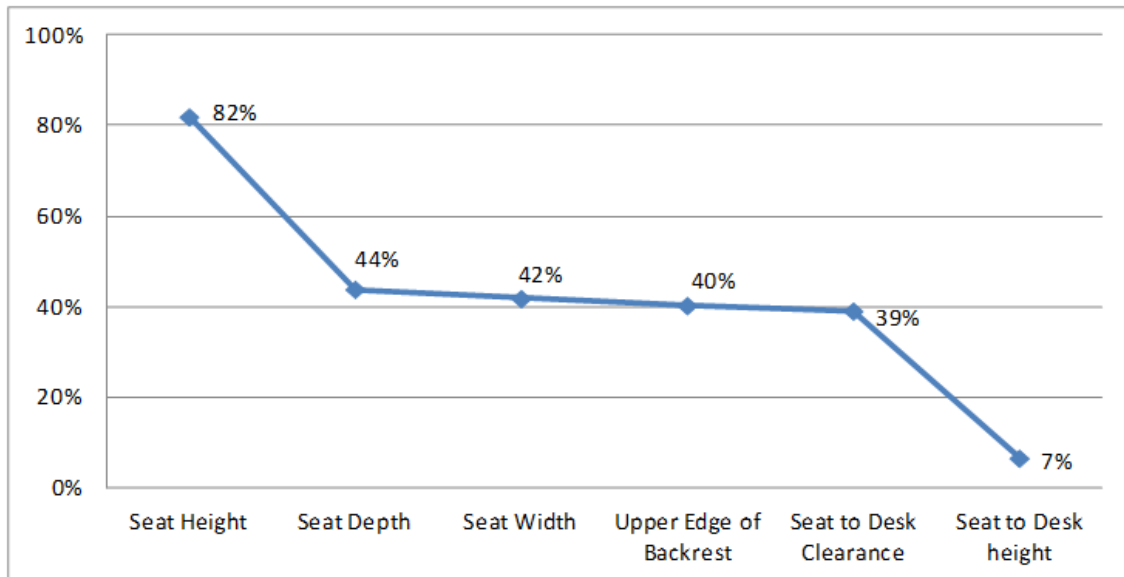


Figure 6.5. Cumulative fit for the analysed furniture dimensions

6.4. Discussion

This study sample was defined by the use of a cluster design regarding the socio-economic levels. The results confirm that there is a difference between dimensions when considering the different socio-economic levels of the students, particularly between the high and the other socio-economic levels.

Positive secular trend was found in the four analysed measures in almost all ages and gender. Regarding S, the average positive secular trend per decade is 1.4 cm and 1.1 cm for female and male, respectively. The results are very similar to the ones presented by Peebles and Norris (1998), where mean male S increased by 1.7 cm and mean female S increased by 1.2 cm during the period from 1981 to 1995 in the UK. However, these amounts are lower than those presented by Fredriks et al. (2000), with positive secular change from 2.7 cm/decade (1955–1965) to 2.0 (1965–1980) and 1.3 cm/decade (1980–1997). HW is the only measure presented where the females at the oldest ages had larger mean values compared with the males in both samples. Similar results were obtained from Mirmohammadi et al. (2013), where the girls from 7 to 11 years old presented higher values of Buttock width or HW than males from the Fars, Kurd, Baluch, Turk and Arab ethnicity.

At first glance, the level of SH match is better than any other studies published about this subject (Afzan et al. 2012, Castellucci et al. 2010, Gouvali and Boudolos 2006, Jayaratne 2012, Parcels et al. 1999, Ramadan 2011, Van Niekerk et al. 2013); however, it is important to remember that:

- This analysis was made based on the application of a standard and not on the evaluation of the actual school furniture.
- Similar results were obtained by Molenbroek et al. (2003), while analysing the Proposal prEN 1729.
- These dimensions do not reach the level of match considered for a good size design of 90% of the population.

The SH results could support the hypothesis that furniture selection can be done more efficiently using PH, since 18% of the students will present SH mismatch and S of the school children was used to select the furniture.

Regarding SD, the 42.8 of low mismatch (Table 6.5.) could be influenced by the increase in the BPL measure (Figure 6.3.). These results are in accordance with studies undertaken elsewhere in the world, involving the analysis of used school furniture (Batistão et al. 2012, Brewer et al. 2009, Gouvali and Boudolos 2006).

The highest values of mismatch will be presented in DH. A number of the studies that were focused on this furniture dimension and applied the same equation have reported almost 100% high mismatch (Batistão et al. 2012, Brewer et al. 2009, Gouvali and Boudolos 2006, Parcels et al. 1999). It is important to note that it is likely that the formulation of the applied equation (Equation 6) may include some problems and thus needs to be evaluated in detail, both in the field and in the laboratory (Castellucci et al., 2014).

Despite the fact that this study has included a very large sample of participants and an extensive database, it should be acknowledged that the conclusion of this study are also limited by the fact that these are based on the analysis of a specific region of Chile. Nevertheless, it is the authors' belief that the same conclusion can be observed in others regions or even in other countries.

Another aspect that should be emphasised is that it is not possible to analyse the mismatch levels with the data available from the study carried out in 1990. The available data refer only to the mean and standard deviation for each anthropometric measure and by each age group. Despite that, authors believe that the positive secular trend observed in this study may have a big impact on the increasing mismatch level. Furthermore, similar ideas were presented by Nadadur and Parkinson (2013), when comparing the body measures for the US population in the early 2000s and by projecting it to the year 2020, assuming a

similar period to the currently study (1990-2012). Based on the US population, the authors refer that a new set of measures for a seat specification consisted of 500 mm width, 430 mm depth and 315–545 mm height adjustability. These specifications achieve a 99.8% match for the current US population and an estimated match level of 90% for the US population in 2020. Also, these authors concluded that ergonomic design concepts can be used in conjunction with forecasts of secular trends to develop certain categories of products, prolonging their lifetime.

6.5. Conclusion

The Chilean student population has increased in S over the past two decades. This important positive secular trend was also observed in other anthropometric measures, such as PH, HW and BPL.

According to the obtained data, it can be concluded that using the Chilean Standard data for furniture size selection will result in a high level of mismatch regarding DH and SD. In this respect, special attention should be drawn to the 18% of mismatch observed in SH, since this measure is the starting point and the most important variable for furniture selection. Furthermore, these results can be used to support the use of PH as the anthropometric measure for classroom furniture selection, instead of the generally used S. Finally, it should be highlighted that it is of paramount importance that the considered values for students anthropometrics in the Chilean Standard can be monitored and updated to reflect the observed changes in the student population, namely to reflect the secular growth observed in this population. This update minimises the observed mismatch and thus the potential postural problems.

References

- Afzan, Z., S. Hadi, B. Shamsul, H. Zailina, I. Nada, and A. Rahmah, A. 2012. "Mismatch between school furniture and anthropometric measures among primary school children in Mersing, Johor, Malaysia." *Network of Ergonomics Societies Conference (SEANES)*, Southeast Asia.
- Agha, S. R. 2010. "School furniture match to students' anthropometry in the Gaza Strip." *Ergonomics* 53 (5): 344–354.
- Batistão, M. V., A. C. Sentanin, C. S. Moriguchi, G. Hansson, H. J. C. Coury, and T. Sato. 2012. "Furniture dimensions and postural overload for schoolchildren's head, upper back and upper limbs." *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1): 4817-4824.

- Brewer, J. M., K. G. Davis, K. K. Dunning, and P. A. Succop. 2009. "Does ergonomic mismatch at school impact pain in school children?" *Work: A Journal of Prevention, Assessment & Rehabilitation* 34 (4): 455–464.
- Castellucci, H. I., P. M. Arezes, and C. A. Viviani. 2010. "Mismatch Between Classroom Furniture and Anthropometric Measures in Chilean Schools." *Applied Ergonomics* 41 (4): 563–568.
- Castellucci, H.I., P. M. Arezes, and J.F.M. Molenbroek. 2014. "Applying different equations to evaluate the level of mismatch between students and school furniture." *Applied Ergonomics*, DOI: 10.1016/j.apergo.2014.01.012.
- Chaffin, D., and G. Anderson. 1991. *Occupational Biomechanics*, 2nd edition. New York: John Wiley.
- Cotton, L. M., D. G. O'Connell, P. P. Palmer, and M. D. Rutland. 2002. "Mismatch of school desks and chairs by ethnicity and grade level in middle school." *Work: A Journal of Prevention, Assessment & Rehabilitation* 18 (3): 269–280.
- Dianat, I., M. Ali Karimib, A. Asl Hashemic, and S. Bahrampour. 2013. "Classroom furniture and anthropometric characteristics of Iranian high school students: Proposed dimensions based on anthropometric data." *Applied Ergonomics* 44 (1): 101–108.
- Evans, W. A., A. J. Courtney, and K. F. Fok. 1988. "The design of school furniture for Hong Kong school children: an anthropometric case study." *Applied Ergonomics* 19 (2): 122–134.
- Fallon, E., and C. Jameson. 1996. An ergonomic assessment of the appropriateness of primary school furniture in Ireland. In: Ozok, A.F., and Salvendy, G (Eds.), *Advances in Applied Ergonomic*. USA: West Lafayette.
- Feathers, D., S. Pavlovic-Veselinovic, and A. Hedge. 2013. "Measures of fit and discomfort for elementary school children in Serbia." *Work: A Journal of Prevention, Assessment & Rehabilitation* 44 (1):S73-81.
- Fredriks A. M., S. Van Buuren, R. J. Burgmeijer, J. F. Meulmeester, R. J. Beuker, E. Brugman, M. J. Roede, S. P. Verloove-Vanhorick, and J. Wit. 2000. "Continuing positive secular growth change in The Netherlands 1955-1997." *Pediatric Research* 47 (3): 316–23.
- García-Acosta, G., and K. Lange-Morales. 2007. "Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric costs." *Ergonomics* 50 (10): 1626–1642.
- García-Molina, C., R. Moraga, L. Tortosa, and V. Verde. 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico*. Valencia: Instituto Biomecánico de Valencia.
- Gouvali, M. K., and K. Boudolos. 2006. "Match between school furniture dimensions and children's anthropometry." *Applied Ergonomics* 37 (6): 765-773.
- Gutiérrez, M., and E. Apud. 1992. "Estudio antropométrico y criterios ergonómicos para la evaluación y diseño de mobiliario escolar." *Cuaderno Médico Social* 33:72–80.

- Hauspie, R., M. Vercauteren, and C. Susanne. 1996. "Secular changes in growth." *Hormone Research* 45:8–17.
- Helander, M. 1997. Anthropometry in workstation design. In M. Helander (Ed.), *A Guide to the Ergonomics of Manufacturing*. London: Taylor & Francis.
- Hibaru, T., and T. Watanabe. 1994. A procedure for allocating chairs to school children. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. London: Taylor & Francis.
- INN (Instituto Nacional de Normalización Chile). 2002. Norma Chilena 2566. Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales. Santiago: INN.
- Jayarathne, K. 2012. "Inculcating the Ergonomic Culture in Developing Countries: National Healthy Schoolbag Initiative in Sri Lanka." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 54 (6): 908-924.
- Khalil, T. M., E. M. Abdel-Moty, R. S. Rosomoff, and H. L. Rosomoff. 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. New York: Van Nostrand Reinhold.
- Lueder, R., and V. Berg Rice. 2008. *Ergonomics for children*. London: Taylor & Francis.
- Milanese, S., and K. Grimmer. 2004. "School furniture and the user population: an anthropometric perspective." *Ergonomics* 47 (4): 416-426.
- Mirmohammadi, S. J., R. Hafezi, A. H. Mehrparvar, R. S. Gerd-faramarzi, M. Mostaghaci, R. J. Nodoushan, and B. Rezaeian. 2013. "An epidemiologic study on anthropometric dimensions of 7-11-year-old Iranian children: considering ethnic differences." *Ergonomics* 56 (1): 90-102.
- Mokdad, M., and M. Al-Ansari. 2009. "Anthropometrics for the design of Bahraini school furniture." *International Journal of Industrial Ergonomics* 39 (5): 728–735.
- Molenbroek, J., and Y. Ramaekers. 1996. Anthropometric design of a size system for school furniture. In S.A. Robertson (Ed.), *Proceedings of the Annual Conference of the Ergonomics Society: Contemporary Ergonomics*. London: Taylor & Francis.
- Molenbroek, J. F. M., Y. M. T. Kroon-Ramaekers, and C. J. Snijders. 2003. "Revision of the design of a standard for the dimensions of school furniture." *Ergonomics* 46 (7): 681-694.
- Muzzo, B. 2003. "Crecimiento normal y patológico del niño y del adolescente." *Revista Chilena de Nutrición* 30: 92–100.
- Nadadur, G., and M. Parkinson. 2013. "The role of anthropometry in designing for sustainability." *Ergonomics* 56 (3): 422-439
- Occhipinti, E., O. Colombini, C. Frigo, A. Pedotti, and A. Grieco. 1985. "Sitting posture: analysis of lumbar stresses with upper limbs supported." *Ergonomics* 28 (9): 1333-1346.

- Orborne, D. J. 1996. *Ergonomics at Work: Human Factors in Design and Development*. 3rd edition. Chichester: John Wiley & Sons.
- Oyewole, S. A., J. M. Haight, and A. Freivalds. 2010. "The ergonomic design of classroom furniture/computer work station for first graders in the elementary school." *International Journal of Industrial Ergonomics* 40 (4): 437–447.
- Panagiotopoulou, G., K. Christoulas, A. Papanickolaou, and K. Mandroukas. 2004. "Classroom furniture dimensions and anthropometric measures in primary school." *Applied Ergonomics* 35 (2): 121-128.
- Parcells, C., M. Stommel, and R.P. Hubbard. 1999. "Mismatch of classroom furniture and student body dimensions." *Journal of Adolescent Health* 24 (4): 265–273.
- Peebles, L., and B. Norris. 1998. *Adultdata. The Handbook of Adult Anthropometric and Strength Measurements—Data for design safety*. London: Department of Trade and Industry.
- Pheasant, S. 1991. *Ergonomics, Work and Health*. Hong Kong: Macmillan.
- Pheasant, S. 2003. *Bodyspace*. 2nd edition. London: Taylor & Francis.
- Ramadan, M. Z. 2011. "Does Saudi school furniture meet ergonomics requirements?" *Work: A Journal of Prevention, Assessment & Rehabilitation* 38 (2): 93–101.
- Savanur, C. S., C. R. Altekari, and A. De. 2007. "Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions." *Ergonomics* 50 (10): 1612-1625.
- Steenbekkers, L. 1993. *Child development, design implications and accident prevention*. Delft, The Netherlands: Delft University Press.
- Tanner, J. 1986. Growth as a mirror of the condition of society: secular trends and class distinctions. In: Demirjian, A. (Ed.). *Human Growth: A Multidisciplinary Review*. London: Taylor and Francis.
- Tanner, J. 1992. "Growth as a measure of the nutritional and hygienic status of a population." *Hormone Research* 38 (1):106–115.
- Troussier, B., C. Tesniere, J. Fauconnier, J. Grisons, R. Juvin, and X. Phelip. 1999. "Comparative study of two different kinds of school furniture among children." *Ergonomics* 42 (3): 516-526.
- UNESCO Santiago, Ministerio de Educación de Chile. 2001. *Guía de recomendaciones para el diseño del mobiliario escolar Chile*. Santiago: UNESCO, MINEDUC
- Van Niekerk, S., Q. A. Louw, K. Grimmer-Somers, J. Harvey, and K. J. Hendry. 2013. "The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school." *Applied Ergonomics* 44 (3): 366–371.

Yeats, B. 1997. "Factors that may influence the postural health of schoolchildren (K-12)." *Work: A Journal of Prevention, Assessment & Rehabilitation* 9 (1): 45-55.

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CHAPTER 7| Analysis of the most relevant anthropometric dimensions for school furniture selection based on a study with students from one Chilean region

Paper published (online) August 2014 as:

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Most of the worldwide standards used for furniture selection suggest the use of the Stature of the school children, assuming that all the other anthropometric characteristics will also be appropriate. However, it is important to consider that students' growth differ with age. The aim of this study is to determine if Popliteal Height can be used as a better, or more adequate, measure for classroom furniture selection when comparing with Stature. This study involved a representative group of 3,046 students from the Valparaíso Region, in Chile. Regarding the methodology, eight anthropometric measures were gathered, as well as six furniture dimensions from the Chilean standard. After assigning the level of school furniture using Stature and Popliteal Height to each of the students, six mismatch equations were applied. The results show that when using Popliteal Height, higher levels of match were obtained for the two more important furniture dimensions. Additionally, it also presents a better cumulative fit than Stature. In conclusion, it seems that Popliteal Height can be the most accurate anthropometric measure for classroom furniture selection purposes.

Keywords: School furniture, selection, anthropometry, mismatch measures.

7.1. Introduction

School work requires students to spend long hours sitting down. Considering this, as well as the potential inadequate use of school furniture, it is likely that some anatomical-functional changes and problems in the learning process may occur (García-Acosta and Lange-Morales, 2007; Trevelyan and Legg, 2006; Milanese and Grimmer, 2004; Hira, 1980). This situation causes an increased concern about the school classrooms, particularly about the study and design of school furniture suitable to the needs of the students and the appropriate dimensions according to the students' anthropometrics characteristics. Worldwide, it is possible to observe a great number of studies regarding the students' anthropometric

characteristics, with the aim of generating safer school furniture (Agha, 2010; Dianat et al., 2013; Evans et al., 1988; Garcia-Acosta and Lange-Morales, 2007; Musa, 2011; Oyewole et al., 2010; Savanur et al., 2007). Furthermore, there is an increase in the number of standards regarding school furniture in different countries, such as: Chile (INN, 2002), Colombia (ICONTEC, 1999), the European Union (CEN, 2012), Japan (JIS, 2011) and United Kingdom (BSI, 2006).

Anthropometric information for chair design is mainly concerned with providing data on the Stature of the people for whom the seats are designed (Evans et al., 1988; Kayis, 1991). Furthermore, most of the standards that are published worldwide for furniture selection tend to use, as a reference, Stature (S) as the anthropometric dimension of the school children, assuming that all the other anthropometric characteristics are also appropriate. However, it is important to remember that student growth differs with ages. For example, before puberty, the legs grow more rapidly than the trunk and in adolescents, the growth spurt is largely in the trunk (Bass et al., 1999). Also, Lueder and Rice (2008) recommended that for designing school furniture it may be useful to consider how children develop and mature, as well as to incorporate features that accommodate a wide range of ages in good postures. The body proportion, i.e., the proportions related to the S between different segments of the body, may be helpful for this situation since it is a scaling relation calculated with a ratio of one body dimension to a specific reference dimension. The most common reference dimension is the Stature (Roebuck et al., 1975).

Some authors (Cho, 1994; Hibarú and Watanabe, 1994; Molenbroek et al., 2003; Noro and Fujita, 1994) suggest that the furniture selection can be done more efficiently if the Popliteal Height (PH) is used instead of S. Molenbroek et al. (2003), demonstrated, by using ellipses, that the seat height proposed in the standard PrEN 1729 is too high for most of the children with S of 1,200 mm. Hibarú and Watanabe (1994) found that the chair size selection was strongly correlated with the PH in 124 students from 4th grade. Another, more complex system was also developed to allocate school furniture by Noro and Fujita (1994). This system is based on the physical images of students and it considered the different variables like PH, S, school grade and physical condition (slim, average and obese). However, there is a controversial point raised between the authors that proposed PH for allocation to the school furniture, namely the fact that, as reported by Noro and Fujita (1994), there is the need to make accurate measurement of PH and this requires experience and skills. On the other hand, Molenbroek et al. (2003) suggested that current knowledge about the use and the measurement of PH in a school class is absent. Nevertheless, the authors assumed that this is not necessarily more difficult and/or time consuming compared to the measurement of S if some measurement strategies are applied, such as the example shown in Figure 7.1. (Molenbroek et al., 2003).

The aim of this study is to determine if PH can be used as a better and most accurate measure for classroom furniture selection rather than using S.



Figure 7.1. Evaluation of Popliteal Height with the “Peter lower leg meter”

7.2. Methodology

7.2.1. Participants

It is important to mention that, in Chile, growth seems to be clearly influenced by socio-economic aspects, where it has been observed that children from higher socio-economic levels are taller than those of lower and medium socio-economic levels (Castellucci et al., 2010; Muzzo, 2003). On this basis, the selection used a stratified random sample regarding the three types of elementary school administrations in Chile (public, semi-public and private), as well as the corresponding financial situation of the students.

The estimated student population of basic and secondary schools in the Valparaíso Region during 2010 was 243,490 students. Considering a 50% prevalence of school furniture mismatch ($p=0.5$ to obtain the largest sample), with 3% accuracy, 95% confidence intervals, and 15% of loss, the theoretical sample size is 1,251 students. However, based on the Chilean school education system, every school has 12 grades, with students ranging from the age of 6 to 18 years old. In order to cover all of them, it was decided to use a random sample of at least 20 students per grade, keeping the proportionality of each cluster. This cross-sectional study involved a representative group of 3,046 participants (1,382 female and 1,664 male students), with ages ranging from 6 to 18 years old (11.7 ± 3.5), from 18 schools that were randomly selected from a list given by the Regional Ministerial Secretary of Education.

The study started after its approval by the Committee of Ethics at the School of Medicine from the Universidad de Valparaíso. Permission to conduct this research was obtained also from the Regional Ministerial Secretary of Education and from the headmaster of each of the considered schools. Additionally, written consent was obtained from parents and students before starting the measurement procedures.

7.2.2. Furniture reference dimensions

Table 7.1. presents the furniture dimensions from the five levels of furniture dimensions indicated in Chilean Standard 2566 (INN, 2002), which were utilized in the current study. Also, Figure 7.2. shows a representation of the furniture dimensions.

Table 7.1. School furniture analysed in this study

Dimension	Definition	Recommended value by Chilean Standard 2566 (in cm)				
		1	2	3	4	5
SH	vertical distance from the floor to the middle point of the front edge of the sitting surface.	30	34	38	41	45
SD	distance from the back to the front of the sitting surface.	27	29	33	39	39
SW	horizontal distance between the lateral edges of the sitting surface.	34	34	38	40	40
UEB	vertical distance between the middle points of the upper edge of the backrest and the top of the sitting surface.	27	29	32	37	37
SDC	vertical distance from middle point of the front edge of the sitting surface to the lowest structure point below the desk.	14	16	18	20	21
DH	vertical distance from the floor to the top of front edge of the desk.	51	57	63	68	73
Reference Stature	range of stature considered to assign the levels of school furniture from the Chilean standard.	[110-123]	[123-137]	[137-151]	[151-168]	[168-184]

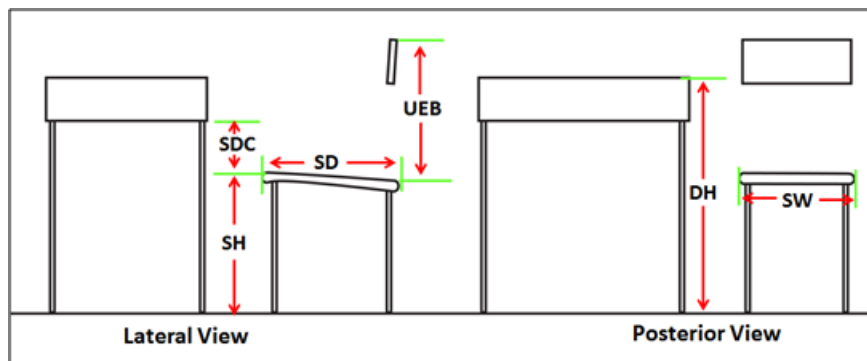


Figure 7.2. Furniture dimensions measured in the study

7.2.3. Anthropometric measure

The anthropometric dimensions were collected from the right side of the subjects while they were sitting in an erect position on a height-adjustable chair with a horizontal surface, with their legs flexed at a 90° angle, and with their feet flat on an adjustable footrest. During the measurement process, the subjects were without shoes and were wearing shorts and T-shirts (ISO, 2008).

All measurements were taken with a portable anthropometer (Holtain), with an exception made to subjects' Stature, which was measured with a stadiometer.

The anthropometric measures considered and collected during this study are presented and defined in Table 7.2. and Figure 7.3.

Table 7.2. Anthropometric measurements considered in the study

Anthropometric measurements	Definition
Shoulder height sitting (SHS)	Vertical distance from subject's seated surface to the acromion.
Elbow height sitting (EHS)	Taken with a 90° angle el-bow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
Thigh thickness (TT)	The vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
Buttock popliteal length (BPL)	Taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface.
Popliteal height (PH)	Measured with 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface).
Subscapular height (SUH)	The vertical distance from the lowest point (inferior angle) of the scapula to the subject's seated surface.
Hip width (HW)	The horizontal distance measured in the widest point of the hip in the sitting position.
Stature (S)	Determined as the vertical distance between the floor and the top of the head, and measured with the subject erect and looking straight ahead (Frankfort plane).

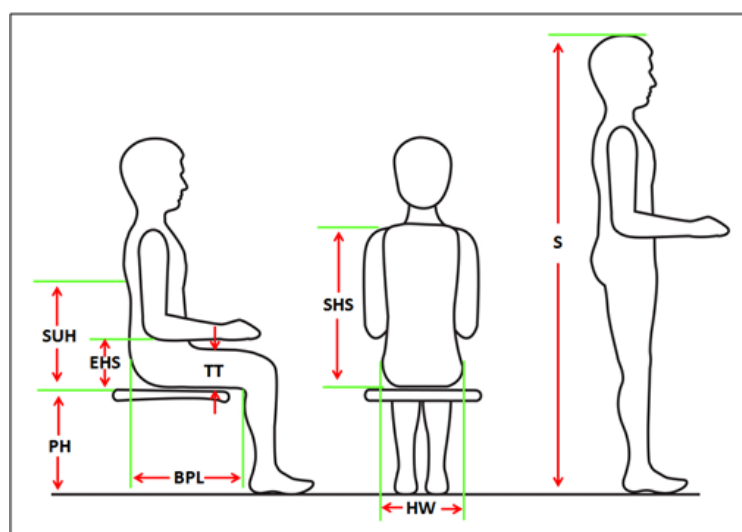


Figure 7.3. Anthropometric measures considered in the study

7.2.4. Mismatch equations

Figure 7.4. shows the procedure for assigning the level of school furniture and analyzes the level of mismatch. The level of school furniture was assigning using S – “Selection by Stature” (SbS) – as the Chilean standard recommend following different intervals for example. For example, if the student’s stature is 167 cm the school furniture level will be the 4th. The school furniture was also assigned using PH – “Selection by Popliteal Height” (SbPH) – it is important to mention that 2 cm were considered for SC, as an example if the same subject presents 43 cm of PH plus the 2 cm of SC the total value will be 45 cm and the students will use the 5th level. After having done this procedure to each of the participants in the sample, the mismatch equations proposed by Castellucci et al. (2014) were applied (Table 7.3.).

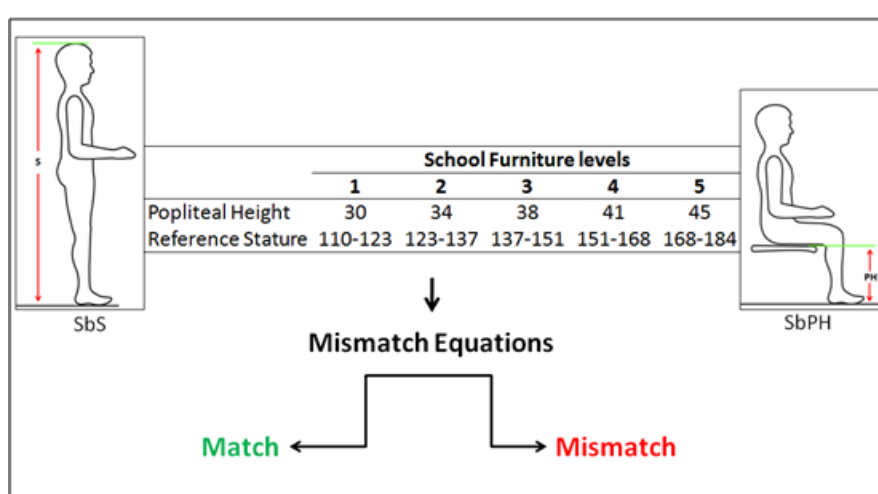


Figure 7.4. Procedure for assigning the level of school furniture and analysing the level of mismatch

Table 7.3. shows three one-way equations to test the level of mismatch of SW, UEB and SDC. For the one-way equations only two categories, or levels, were defined: “Match” and “Mismatch”.

Equation 3 tests SW using HW considering only one limit, as mentioned by Pheasant (2003), and the cardinal constraints of anthropometrics considered in this equation are clearance since SW has to be higher than HW to avoid discomfort and mobility restrictions (Evans et al., 1988; Helander, 1997; Osborne, 1996; Oyewole et al., 2010). Following the same cardinal constraints of anthropometrics, Equation 5 shows that the SDC has to be 2 cm higher than TT to allow the students to push the chair under the table. Finally, Equation 4 shows that UEB need to be lower than SUH to generate enough free space for scapula mobility.

In Table 7.3., it is possible to observe three two-way equations (Equation 1, 2 and 6), where both the minimum and maximum limits were considered. In this case, three categories were defined: (i) "Match" level, when the furniture dimensions are between the limits; (ii) "High mismatch" level, when the

maximum limit of the equation is lower than the furniture dimension, indicating that the furniture dimension is higher than needed; and finally, (iii) "Low mismatch" level, when the minimum limit of the equation is higher than the furniture dimension – in this case, the furniture dimensions are lower than the recommended level.

Table 7.3. Mismatch Equations applied in the study

School Furniture Dimension	(mis)match equation
SH	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$
SD	Eq. 2: $0.80BPL \leq SD \leq 0.95BPL$
SW	Eq. 3: $HW < SW$
UEB	Eq. 4: $SUH \geq UEB$
SDC	Eq. 5: $TT + 2 < SDC$
DH	Eq. 6: $(SH - (\sin X^\circ SD)) + EHS \leq DH \leq (SH - (\sin X^\circ SD)) + EHS * 0.8517 + SHS * 0.1483$

In first place, the SH equation is based on the height of PH (Equation 1). It also considers the biomechanics of the knee, where the lower leg forms a 5-30° angle relative to the vertical (Gouvali and Boudolos, 2006). This situation is reflected by the different values of cosines (cos). The formula shows that the SH has to be higher than $\cos 30^\circ$ of the PH plus the shoe correction (SC) to avoid an extension of more than 30° relative to the vertical. This is relevant, since with more extension, the feet will not be placed flat on the floor or the thighs would not be supported enough, causing discomfort. On the other hand, SH has to be lower than $\cos 5^\circ$ of the PH plus SC to ensure that the student will sit in a chair high enough so that both feet are placed entirely on the floor, but also avoiding the compression in the buttock region (García-Molina et al., 1992). In this study, 2 cm were considered for the SC. However, it is also necessary to consider that SC may naturally vary according to culture, fashion, and country. For example, other authors also recommend shoe corrections with values of 2 cm (Agha, 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006), 2.5 cm (Herzberg, 1972; Van Niekerk et al., 2013) and 4.5 cm (Pheasant, 1984).

Equation 2 evaluates the SD by using the percentage of Buttock Popliteal Length (BPL). The support of at least 80% of BPL is needed to avoid the extra-pressure on the back of the thighs, which could cause discomfort (Pheasant, 2003). However, the SD cannot be higher than 95% of the BPL because the student will not be able to use the backrest of the seat and, consequently, will not be able to support the lumbar spine without compression of the popliteal surface (Milanese and Grimmer, 2004). To avoid this it is likely that the student will generally move their buttocks forward toward the edge of the seat, as suggested by Panagiotopoulou et al. (2004). This improper usage of the backrest causes kyphotic posture (Khalil et al., 1993; Pheasant, 1991).

Finally, the last two-way equations are the DH equation, which was used for the first time in the context of school furniture by Parcels et al. (1999) and considered that acceptable elbow rest height (AERH) depends not only on Elbow Height Sitting (EHS), but also on the shoulder flexion and abduction angles. To determine AERH it is necessary to know the SHS and EHS, since by subtracting these anthropometric measures the Upper Arm Length (U) can be calculated. Shoulder Flexion (θ) and Shoulder Abduction (β) need to also be considered in the following main formula:

$$\text{AERH} = \text{EHS} + U [(1 - \cos\theta) + \cos\theta (1 - \cos\beta)] \quad \text{Eq. (7)}$$

Furthermore, considering Chaffin and Anderson's principles (1991) of acceptable shoulder flexion angles from 0° to 25° and shoulder abduction from 0° to 20° , the student's minimum DH is determined by the minimum shoulder flexion and abduction of 0° the corresponding cosines are 1. Given that the cosines are monotone functions of the angles, the minimum AERH is determined by the EHS, since:

$$\text{Minimum AERH} = \text{EHS} + U [(1 - 1) + 1 (1 - 1)] \quad \text{Eq. (8)}$$

On the other hand, the maximum AERH is calculated by considering the 25° of shoulder flexion and 20° of shoulder abduction, where the corresponding cosines are 0.9063 and 0.9397, respectively. The equation proposed is:

$$\begin{aligned} \text{Maximum AERH} &= \text{EHS} + U [(1 - 0.9063) + 0.9063 (1 - 0.9397)] \quad \text{Eq. (9)} \\ &= \text{EHS} + U (0.1483) \\ &= \text{EHS} + 0.1483 \text{ SHS} - 0.1483 \text{ EHS, since } U = \text{SHS} - \text{EHS} \\ &= 0.8517 \text{ EHS} + 0.1483 \text{ SHS} \end{aligned}$$

It is important to mention that Equations 8 and 9 only considered the distance from the seat to the table. Due to this, the minimum and maximum DH, presented in Equation 6, considered the SH and the backward slope of the chairs, since the elbow is aligned with the back of the seat and is lower than the front edge. Regarding the seat angle, the standard considered a 4° backward slope or negative seat angle.

7.2.5. Statistical analysis

All the anthropometric data were analyzed using MS Excel and SPSS (v22.0). The Pearson Correlation coefficient was applied between the anthropometric measures, since this is a measure of the strength of

the linear relationship between two variables. The dispersion graphics of S and PH with the others anthropometric measures are presented in appendice.

After the different equations were applied, categorical data (Low Mismatch, Match and High Mismatch) were analyzed. The Kappa Statistic was applied to measure the degree of concordance between the two anthropometric measures used for furniture selection (Stature/Popliteal Height).

Kappa is a good tool to assess inter-observer reliability, particularly for qualitative items (match/mismatch). In this study, it was used to determine the level of inter-observer reliability of the two anthropometric measures used for furniture selection.

7.3. Results and Discussion

7.3.1. Anthropometric

The obtained values from the eight anthropometric measures of all the considered participants are presented by age and split by gender in Table 7.4. and 7.5. for female and male, respectively.

The Pearson Correlation coefficient result shows a strong positive correlation between S and the other anthropometric dimensions gathered in this study, with the following values: PH ($r = 0.95$), BPL ($r = 0.93$), TT ($r = 0.74$), HW ($r = 0.76$), EHS ($r = 0.68$), SUH ($r = 0.90$) and SHS ($r = 0.93$). These results are normally used as a justification to use S for school furniture selection. Furthermore, comparing with S the PH measure presents a weaker positive correlation with the following values: BPL ($r = 0.89$), TT ($r = 0.68$), HW ($r = 0.69$), EHS ($r = 0.59$), SUH ($r = 0.82$) and SHS ($r = 0.86$). However, as it was mentioned before, an important issue for school furniture selection is the consideration of the students' stage of growth. To analyze this situation, PH and SHS will be transformed in ratios, in relation to the S, to give indications of body proportions. Steenbekkers (1993) suggested that SHS might be used as a measure of trunk length. When SHS is divided by Stature, it yields a value for trunk length relative to whole body length.

In Figure 7.5., it is possible to observe, at first glance, that males present higher levels of proportion of PH than females, and that there are opposite results for the trunk length ratio. It also shows how the proportion of these dimensions varies with age.

Table 7.4. Anthropometric Female data from the study sample (cm)

Anthropometric dimensions (cm)	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years
	n:98	n:110	n:127	n:123	n:114	n:125	n:135	n:116	n:106	n:105	n:103	n:103	n:17
Stature	119.3±4.8	124.4±5.3	132.3±5.6	137.9±6.3	142.7±7.3	147.5±6.5	153.6±6.5	156.5±6.0	158.3±6.0	158.7±6.2	157.9±5.2	160.6±6.8	159.0±5.5
Shoulder Height Sitting	40.6±2.5	42.8±2.5	45.6±2.5	47.4±2.9	49.3±3.3	51.4±3.1	53.6±2.8	55.6±2.7	56.9±2.7	57.2±2.7	57.2±2.3	58.4±2.8	58.1±3.9
Elbow Height Sitting	16.5±2.4	17.4±2.4	18.4±2.0	19.1±2.3	19.8±2.7	20.3±2.4	21.5±2.6	22.6±2.6	23.6±2.8	23.5±2.6	24.1±2.5	25.0±2.7	25.4±2.1
Subscapular Height	30.3±2.1	31.9±2.3	34.3±2.2	35.5±2.6	36.7±2.7	37.8±2.8	40.3±2.6	41.4±2.2	42.7±2.5	42.9±2.6	43.0±2.1	43.5±2.5	43.8±2.2
Popliteal Height	29.8±1.8	31.6±1.8	34.4±1.8	36.0±1.8	37.3±2.1	38.2±1.9	39.6±1.8	39.9±1.7	40.2±1.9	39.9±2.0	39.8±1.8	40.5±2.0	39.8±1.5
Thigh Thickness	11.0±1.6	11.2±1.6	12.0±1.5	12.8±1.7	12.9±1.6	13.3±1.6	14.4±1.8	14.7±1.7	14.9±1.8	15.3±1.7	14.8±1.8	15.0±1.9	14.9±1.3
Hip Width	26.1±2.5	26.9±2.7	28.6±2.7	30.2±2.8	31.3±3.1	32.3±2.9	34.8±3.3	36.1±3.0	36.7±3.1	37.3±3.1	37.5±2.8	38.2±3.2	37.5±2.9
Buttock Popliteal Length	33.9±2.0	35.6±2.2	38.1±2.5	39.9±2.3	41.5±2.8	43.1±2.7	44.9±2.9	45.9±2.6	45.9±2.9	46.4±2.8	46.2±2.7	46.7±2.7	46.2±2.1

Table 7.5. Anthropometric Male data from the study sample (cm)

Anthropometric dimensions (cm)	6 years	7 years	8 years	9 years	10 years	11 years	12 years	13 years	14 years	15 years	16 years	17 years	18 years
	n:92	n:117	n:134	n:156	n:142	n:152	n:160	n:151	n:121	n:126	n:142	n:102	n:69
Stature	121.7±4.7	126.3±4.5	131.7±5.3	136.1±6.5	143.0±6.8	147.5±7.7	152.7±8.7	160.0±7.4	165.1±8.1	168.2±7.7	170.0±5.5	171.1±6.5	170.4±6.2
Shoulder Height Sitting	41.2±2.2	42.8±2.0	44.9±2.4	46.5±2.6	48.8±2.9	50.6±3.4	52.2±3.6	54.4±3.2	56.7±4.1	57.9±4.0	58.8±3.1	59.6±3.5	59.7±3.9
Elbow Height Sitting	16.7±2.1	17.5±2.2	17.8±2.1	18.4±2.2	19.2±2.5	19.6±2.6	20.4±2.7	20.6±2.7	22.3±2.9	23.0±3.2	23.7±3.1	24.2±3.1	24.7±2.8
Subscapular Height	30.8±2.0	32.1±2.1	33.5±2.2	34.4±2.5	36.1±2.3	37.4±3.2	38.7±3.2	40.4±2.9	41.9±3.4	43.2±3.0	44.0±2.5	44.6±2.9	45.0±2.9
Popliteal Height	30.3±1.5	32.4±1.6	34.0±2.0	35.5±2.1	37.6±1.9	38.8±2.1	39.7±2.3	41.7±2.0	42.5±2.3	43.1±2.3	43.3±2.0	43.4±2.0	42.8±1.8
Thigh Thickness	11.1±1.4	11.4±1.7	12.0±1.7	12.5±1.7	13.0±1.7	13.8±1.9	14.4±2.0	14.8±1.7	15.5±2.0	15.5±1.9	16.1±1.8	15.6±1.9	15.8±1.7
Hip Width	25.8±2.2	27.3±3.0	28.7±2.8	29.6±3.2	30.9±3.3	32.4±3.7	32.6±3.4	33.8±3.4	34.8±3.7	35.2±3.2	35.7±3.0	35.9±2.9	36.0±2.9
Buttock Popliteal Length	34.0±2.2	35.4±2.1	37.2±2.2	38.8±2.5	40.9±2.7	42.9±2.9	43.8±3.1	45.8±2.7	47.2±2.9	47.3±2.8	47.5±2.4	47.8±2.3	47.6±2.6

In the case of females after six years old, lower limbs grow more significantly, with the highest value at the age of 10, after that, the values start to decrease faster until 15 years of age. The trunk proportion starts to grow faster at the age of 12, with values that go from 0.349 to 0.366 at the age of 18. Similar results were observed for males PH proportion with differences that had the highest values and who had peak growth that was reached one year later than females. This situation can be explained by the fact that males reach puberty at an older age than females (Burrows et al., 2004). The implications of these results in the anthropometric measure used for furniture selection and the level of mismatch will be explored later in this report.

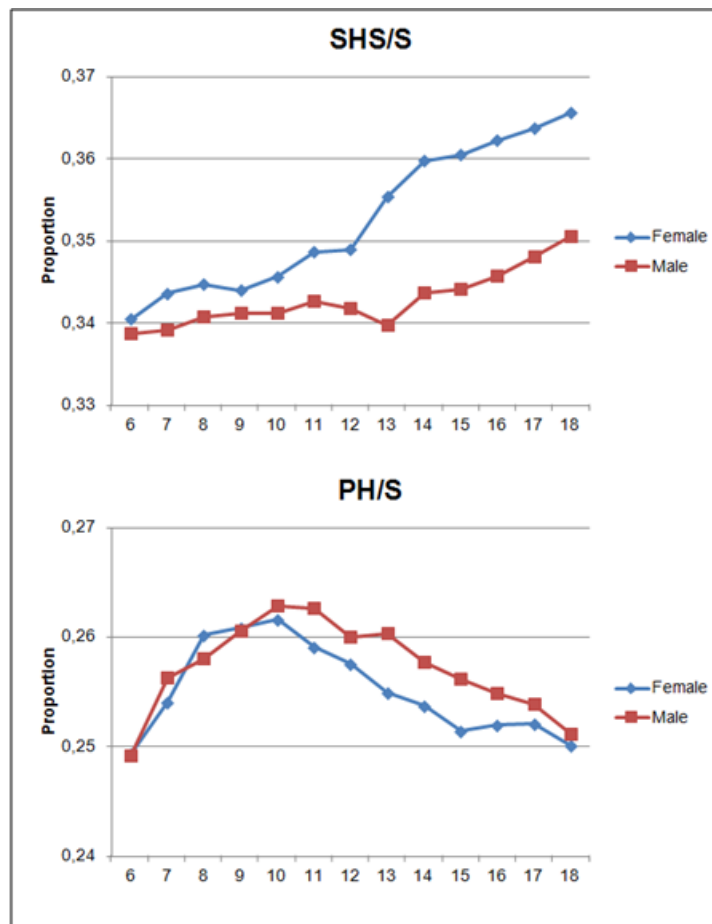


Figure 7.5. Proportion of Shoulder Height sitting (SHS) and Popliteal Height (PH) from Stature (S)

7.3.2. Level of mismatch using Stature or Popliteal Height

Before the presentation of the results, it is important to mention that by using SbPH, 30 students will not find proper school furniture, since all of them present lower PH (with SC) than the minimum considered by the Chilean standard (30 cm). In the case of SbS, 12 students are considered to be out of the reference S range (Table 7.1.), three of them below 110 cm and nine above 184 cm.

As expected, from the analysis of the data in Figure 7.6., when the furniture selection was done using PH, 100% of the students found a perfect fit regarding SH. However, when it was done using the SbS, 16.9% of students found that the chair is too high (High mismatch) and will be unable to rest their feet on the floor properly, thus causing compression of vascular and neural structures going along the popliteal space (Milanese and Grimmer, 2004). Additionally, 1% of the students will use a lower than needed chair, which will increase the compression in the buttock region (García-Molina et al., 1992), while also increasing the degree of lumbar flexion involved in sitting (Pheasant, 2003). The result of Kappa Statistics shows a slight agreement ($k=0.01$) between the two anthropometric measures used for furniture selection. It is important to highlight that SH should be considered as the starting point and the most important variable for the design of the classroom furniture (Castellucci et al., 2010; Molenbroek et al., 2003).

In Table 7.6., it is possible to observe that females present a level of SH mismatch higher than males, this situation can be explain since the males presents higher levels of PH proportion (Figure 7.5.). Furthermore, the females in the age range of 8 to 12 years present the lower level of high mismatch – the age range that achieved the highest level of PH proportion (Figure 7.5.). Similar results are presented by the male population, with the lowest level of high mismatch in the age range of 10 to 13 years, where the levels of PH proportion exceeded 0.26. Furthermore, to strengthen these results, the average of PH proportion for high mismatch, match and low mismatch when SH was SbS were calculated. The results were 0.246 ± 0.008 , 0.259 ± 0.008 and 0.279 ± 0.012 , respectively.

Table 7.6. Percentage of Seat Height “high mismatch” when furniture is selected by Stature

Gender	Students age													Mean
	6	7	8	9	10	11	12	13	14	15	16	17	18	
Female	28,6%	22,7%	12,6%	17,9%	14,0%	13,6%	11,9%	19,0%	18,9%	33,3%	19,4%	21,4%	29,4%	20,2%
Male	28,3%	22,2%	21,6%	15,4%	8,5%	7,2%	10,0%	4,6%	12,4%	12,7%	18,3%	23,5%	26,1%	16,2%

Considering the previously presented results, it is possible to infer that PH is the most accurate anthropometric measure for SH dimension and is heavily influenced by proportion. This situation can be reflected by Reis (2012), who indicates that at the different school phases until the beginning of puberty, one should pay more attention to the height of the seat and, during puberty, the height of the desk deserves more attention, since after six years old, lower limbs grow more significantly and continue to grow faster than other body segments until the onset of puberty, which, in turn, causes the trunk to grow faster again. Also, there are some facts that support PH as a good reference for defining the level of school furniture by using the technique of dividing the cumulative distribution of PH (Evans et al., 1988; Gutierrez and Apud, 1995; UNESCO, 2001), but this is not used for school furniture selection.

Finally, another point to consider is that not only age and gender are key factors for proportion, but also ethnic diversity. Lin et al. (2004) shows that most of the average dimensions and all of the bodily proportions have significant differences among four East Asian peoples (Chinese, Japanese, Korean and Taiwanese).

Figure 7.6. shows too shallow seats for 43% and 46% of the students using SbS and SbPH, respectively. This situation of mismatch shows that the students' thighs would not be supported enough and would generate discomfort (Pheasant, 2003). On the other hand, very low values of high mismatch are observed for SbS (0.4%) and SbPH (0.7%). For this furniture dimension, the Kappa Statistics show a substantial agreement between SbS and SbPH ($k=0.69$).

Finally, Figure 7.6. also presents the highest level of high mismatch for DH, with 82% and 79% when SbS and SbPH are used, respectively. In this situation the students will flex and abduct their upper arms, as well as raise their shoulders. This, in the opinion of García-Molina et al. (1992), may result in more muscle work load, discomfort and pain in the shoulder region. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture. Notwithstanding the large number of students that will have to face this high mismatch, it is important to note that it is likely that the formulation of the applied equation (Equation 6) may include some problems and thus needs to be evaluated in detail, both in the field and in the laboratory (Castellucci et al., 2014). After applying the Kappa Statistic test, it can be concluded that there exists an almost perfect agreement for DH between the two anthropometric measure used for furniture selection ($k=0.82$).

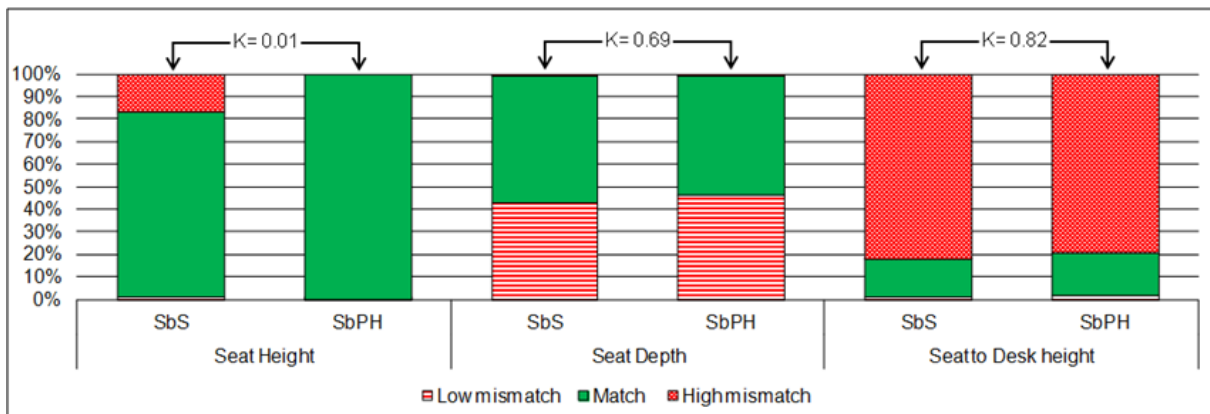


Figure 7.6. (Mis)match percentages for two-way equation considering the two anthropometric measures for school furniture selection

Narrower seats were observed for 7.1% and 8.7% of the students using SbS and SbPH, respectively (Figure 7.7.). According to Helander (1997) and Orborne (1996), with such seats the school children will not be able to dissipate the pressure at the buttock, which will also cause discomfort and mobility restrictions. The Kappa Statistics between SbS and SbPH show an almost perfect agreement ($k=0.86$).

After selecting furniture with SbS and SbPH, 2.1% and 3.9% of the students will find the backrest higher than SUH, respectively (Figure 7.7.). This type of mismatch will result in the compression of the scapula and in a reduction in the arm and trunk mobility (García-Acosta and Lange-Morales, 2007; Orborne, 1996), which can impair task performance and cause awkward postures in order to achieve task goals. In this furniture dimension, the Kappa Statistic indicates a moderate agreement between the two anthropometric measure ($k=0.56$).

SDC mismatched 7.1% and 10.9% of the students, respectively, for SbS and SbPH (Figure 7.7.). In this situation, students will restrain mobility because of the contact of the thighs with the desk (Parcells et al., 1999; Sanders et al., 1993) and because they will not be able to push the chair under the table. The result of Kappa Statistics shows substantial agreement ($k=0.73$) between the two anthropometric measures used for furniture selection.

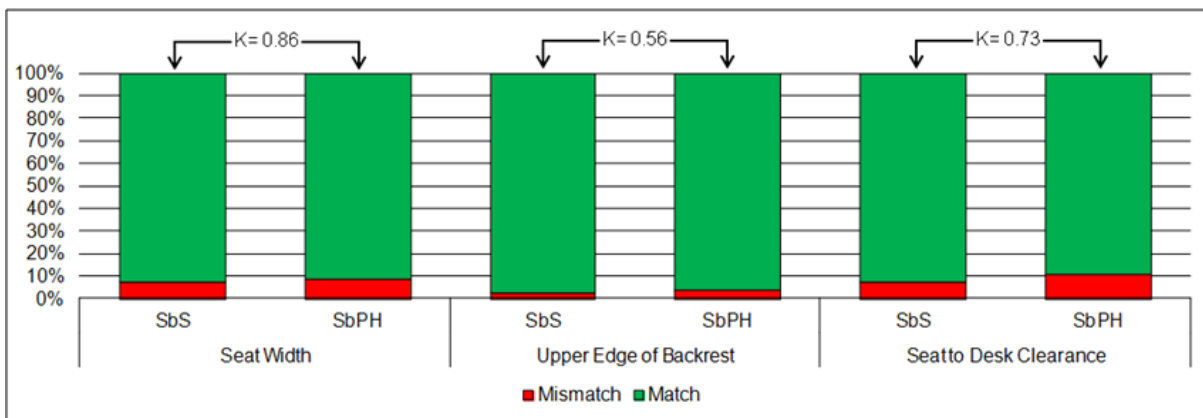


Figure 7.7. (Mis)match percentages for one-way equation considering the two anthropometric measures for school furniture selection

In order to improve the analysis, Figure 7.8. shows the percentage of estimated “cumulative fit” by using the two compared selection approaches, i.e., the SbS and SbPH. The cumulative fit is defined as the match that takes into account the cumulative values of the different furniture dimensions in analysis (Castellucci et al., 2014). The obtained results shows that the higher level of cumulative fit (or match) can be reached by adopting the SbPH. The final results show that only 7% for SbS and 8% for SbPH of the students will fit in the different furniture sizes presented by the Chilean Standard N° 2566. However, these results should be interpreted with caution since, as mentioned before, there is a potential problem in the criteria formulation of Equation 6, which might well be impairing the final results.

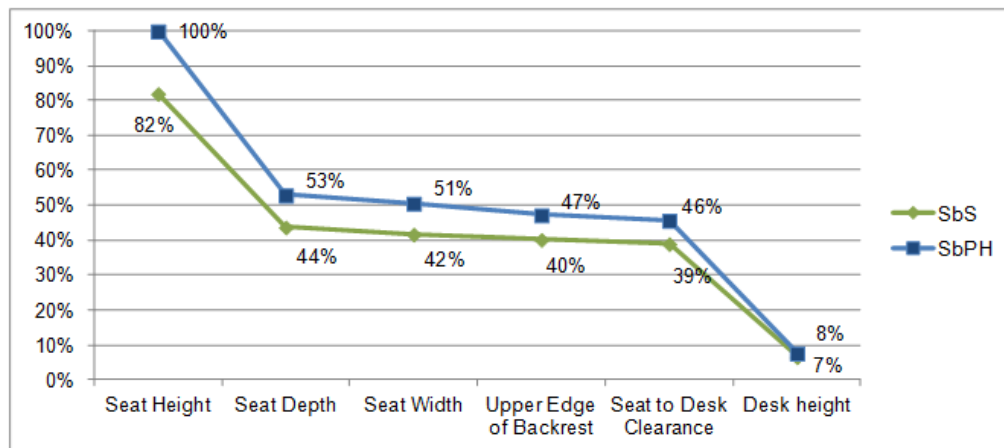


Figure 7.8. Cumulative Fit considering the two anthropometric measures for school furniture selection

7.4. Conclusion

According to the obtained data, it can be concluded that the Chilean students from the Valparaíso Region present differences in the proportion of Popliteal Height and Trunk Length when comparing it across the two genders and different ages. The levels of mismatch, especially for Seat Height, are also influenced by the different Popliteal Height proportions presented by the students during the different stage of growth.

Regarding the anthropometric measure used for furniture selection, it can be concluded that four out of six dimensions present the highest levels of match when the school furniture is SbS. However, for the most important furniture dimensions (Seat Height and Desk Height), it has obtained a better fit when SbPH is used. Furthermore, it can be stated that Popliteal Height is the most accurate, and therefore the most appropriate, anthropometric measure for classroom furniture selection since it presents a better cumulative fit (or match) than Stature.

It should be highlighted that it is somehow not clear why Popliteal Height is not used for furniture selection in the standards published worldwide, since it can be easier to measure this dimension than Stature. Finally, it seems that it will be also important to analyse the Chilean Standard recommended values, since it appears that there is high percentage of mismatch between children's characteristics and the furniture's recommended dimensions.

Appendices

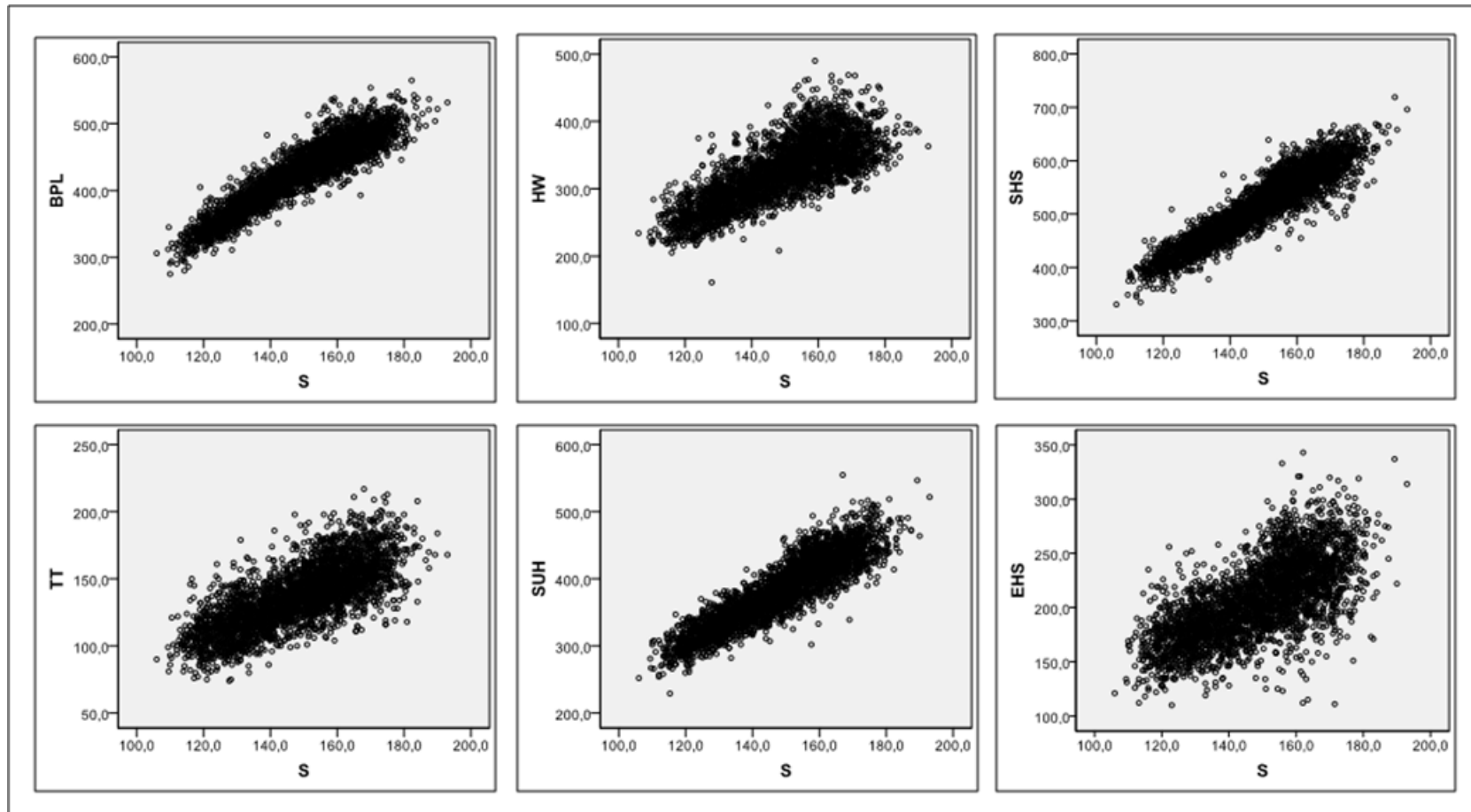


Figure A.7.1. Dispersion graphics of Stature (S) with the remaining considered anthropometric measures: SHS, EHS, SUH, HW, TT and BPL.

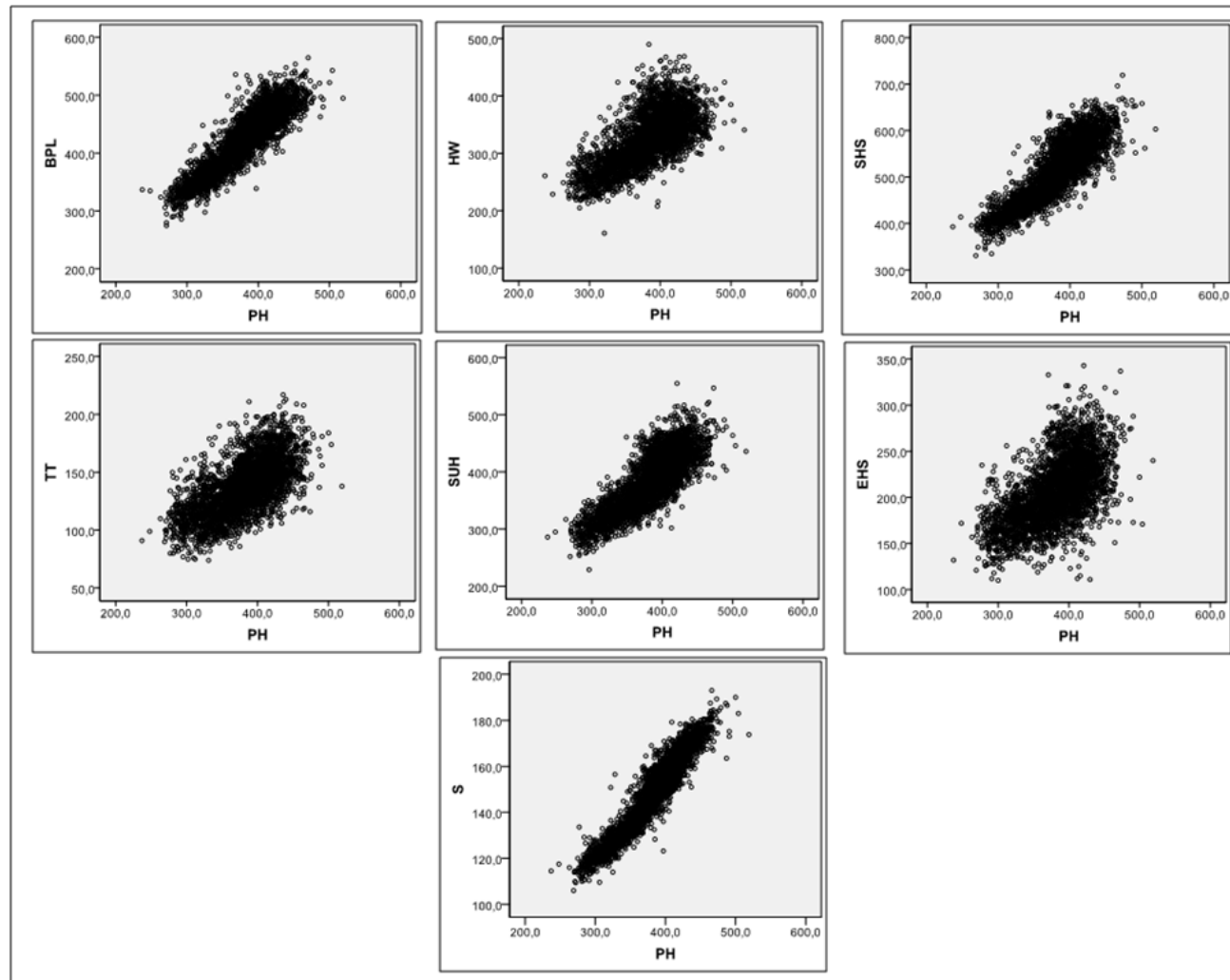


Figure A.7.2. Dispersion graphics of Popliteal Height (PH) with the remaining considered anthropometric measures: SHS, EHS, SUH, HW, TT, BPL and S.

References

- Agha, S., 2010. School furniture match to students' anthropometry in the Gaza Strip. *Ergonomics* 53 (5), 344–354.
- Bass, S., Delmas, P.D., Pearce, G., Hendrich, E., Tabensky, A., Seeman, E., 1999. The differing tempo of growth in bone size, mass and density in girls is region-specific. *Journal of Clinic Investigation* 104 (6), 795–804.
- BSI (British Standard Institution)., 2006. BS EN 1729-1: 2006 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions. UK: BSI.
- Burrows, R., Díaz, N., Muzzo, S., 2004. Variaciones del índice de masa corporal (IMC) de acuerdo al grado de desarrollo puberal alcanzado. *Revista Médica de Chile* 132 (11), 1363-1368.
- Castellucci, H.I., Arezes, P.M., Viviani, C., 2010. Mismatch Between Classroom Furniture and Anthropometric Measures in Chilean Schools. *Applied Ergonomics* 41 (4), 563–568.
- Castellucci, H.I., Arezes, P.M., Molenbroek, J.F.M., 2014. Applying different equations to evaluate the level of mismatch between students and school furniture. *Applied Ergonomics* 45 (4), 1123–1132.
- CEN (European committee for standardization), 2012. PREN 1729-1: Furniture - Chairs And Tables for Educational Institutions - Part 1: Functional Dimensions.
- Chaffin, D., Anderson, G., 1991. *Occupational Biomechanics*, 2nd edition. John Wiley, New York.
- Cho, A., 1994. Fitting the chair to the school child in Korea. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. Taylor & Francis, London.
- Dianat, I., Ali Karimib, M., AslHashemic, A., Bahrapour, S., 2013. Classroom furniture and anthropometric characteristics of Iranian high school students: Proposed dimensions based on anthropometric data. *Applied Ergonomics* 44 (1), 101–108.
- Evans, W.A., Courtney, A.J., Fok, K.F., 1988. The design of school furniture for Hong Kong school children: an anthropometric case study. *Applied Ergonomics* 19 (19), 122–134.
- Garcia-Acosta, G., Lange-Morales, K., 2007. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric criteria. *Ergonomics* 50 (10), 1626–1642.
- García-Molina, C., Moraga, R., Tortosa, L. , Verde, V., 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico*. Instituto Biomecánico de Valencia, Valencia.
- Gouvali, M., Boudolos, K., 2006. Match between school furniture dimensions and children's anthropometry. *Applied Ergonomics* 37 (6), 765-773.
- Gutiérrez, M., Apud, E., 1995. Ergonomía aplicada al diseño de mobiliario escolar." *Cuaderno Médico Social* 36 (3), 18-23.

- Helander, M., 1997. Anthropometry in workstation design. In M. Helander (Ed.), *A Guide to the Ergonomics of Manufacturing*. Taylor & Francis, London.
- Herzberg, H., 1972. Engineering anthropology. In: *Human engineering guide to equipment design*: Van Cott, H.P., and Kincade, R.D. McGraw-Hill, New York.
- Hibaru, T., Watanabe, T., 1994. A procedure for allocating chairs to school children. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. Taylor & Francis, London.
- Hira, D. S., 1980. An ergonomic appraisal of educational desks. *Ergonomics* 23 (3), 213-221.
- ICONTEC (Instituto Colombiano de Normas Técnicas y Certificación), 1999. Norma Técnica Colombiana 4641. Muebles Escolares. Pupitre con Silla para Aulas de Clase. ICONTEC, Bogotá, Colombia.
- INN (Instituto Nacional de Normalización Chile), 2002. Norma Chilena 2566. Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales. INN, Santiago de Chile.
- ISO, 2008. ISO 7250-1: Basic human body measurements for technological design — Part 1: Body measurement definitions and landmarks. International Organization for Standardization, Geneva, Switzerland.
- JIS (Japanese Industrial Standards), 2011. JIS S 1021. School furniture – Desks and chairs for general learning space. JIS, Tokyo, Japan.
- Kayis, B., 1991. Why ergonomic designs in school?, in V. Popovic and M. Walker (eds), *Proceedings of the 27th Annual Conference of the Ergonomics Society of Australia 'Ergonomics and Human Environments'*, Cooloom (Australia: Ergonomics Society of Australia).
- Khalil, T., Abdel-Moty, E., Rosomoff, R., Rosomoff, H., 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. Van Nostrand Reinhold, New York.
- Lin, Y.C., Wang, M.-J.J., Wang, E.M., 2004. The comparisons of anthropometric characteristics among four peoples in East Asia. *Applied Ergonomics*, 35 (2), 173–178.
- Lueder, R., Berg Rice, V., 2008. *Ergonomics for children*. Taylor & Francis, London.
- Milanese, S., Grimmer, K., 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics* 47 (4), 416-426.
- Molenbroek, J., Kroon-Ramaekers, Y., Snijders, C., 2003. Revision of the design of a standard for the dimensions of school furniture. *Ergonomics* 46 (7), 681-694.
- Musa, A., 2011. Anthropometric evaluations and assessment of school furniture design in Nigeria: A case study of secondary schools in rural area of Odeda, Nigeria. *International Journal of Industrial Engineering Computations* 2 , 499–508.
- Muzzo, B. 2003. Crecimiento normal y patológico del niño y del adolescente. *Revista Chilena de Nutrición* 30 (2), 92–100.

- Noro, K., Fujita, T., 1994. A fuzzy expert system for allocating chairs to elementary school children. In: Lueder, R., and K. Noro (Eds.), *Hard Facts about Soft Machines: The Ergonomics of Seating*. Taylor & Francis, London.
- Orborne, D., 1996. *Ergonomics at Work: Human Factors in Design and Development*. 3rd edition. John Wiley & Sons, Chichester.
- Oyewole, S. A., Haight, J. M., Freivalds, A., 2010. The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *International Journal of Industrial Ergonomics*, 40 (4), 437–447.
- Panagiotopoulou, G., Christoulas, K., Papanickolaou, A., Mandroukas, K., 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics* 35 (2), 121-128.
- Parcells, C., Stommel, M., Hubbard, R., 1999. Mismatch of classroom furniture and student body dimensions: Empirical Findings and Health Implications. *Journal of Adolescent Health* 24 (4), 265–273.
- Pheasant, S., 1984. *Anthropometrics: An introduction for schools and colleges (PP7310)*. British Standards Institution, London.
- Pheasant, S., 1991. *Ergonomics, Work and Health*. Macmillan, Hong Kong.
- Pheasant, S., 2003. *Bodyspace*, 2nd edition. Taylor & Francis, London.
- Roebuck, J.A., Kroemer, K.H.E., Thomson, W.G., 1975. *Engineering Anthropometry Method*, 2nd Edition. Wiley, New York.
- Reis, P., Moro, A., Da Silva, J., Paschoarelli, L., Nunes Sobrinho, F., 2012. Anthropometric aspects of body seated in school. *Work: A Journal of Prevention, Assessment & Rehabilitation* 41 (1), 907-914.
- Sanders, M. S., McCormick, E. J., 1993. *Applied anthropometry, work-space design and seating* In *Human Factors in Engineering and Design*. 7th edition. McGraw-Hill, Singapore.
- Savanur, C., Altekari, C., De, A., 2007. Lack of conformity between Indian classroom furniture and student dimensions: proposed future seat/table dimensions. *Ergonomics* 50 (10), 1612-1625.
- Steenbekkers, L., 1993. *Child development, design implications and accident prevention*. Delft University Press, Delft, The Netherlands.
- Trevelyan, F.C., Legg, S.J., 2006. Back pain in school children—Where to from here? *Applied Ergonomics* 37 (1), 45–54.
- UNESCO Santiago, Ministerio de Educación de Chile. 2001. *Guía de recomendaciones para el diseño del mobiliario escolar Chile*. UNESCO, MINEDUC, Santiago de Chile.
- Van Niekerk, S., Louw, Q., Grimmer-Somers, K., Harvey, J., Hendry, K., 2013. The anthropometric match between high school learners of the Cape Metropole area, Western Cape, South Africa and their computer workstation at school. *Applied Ergonomics* 44 (3), 366–371.

CHAPTER 8| An update to the Chilean standard for school furniture dimension specifications

Paper submitted in December 2014 for publication as:

Castellucci, HI, Arezes, PM, Molenbroek, JFM. (n.d.). An update to the Chilean standard for school furniture dimension specifications. *International Journal of Industrial Ergonomics*.

Some countries decide to use standards to define the type of furniture dimensions that should be used according to the students' anthropometric characteristics. The aim of this paper is to generate data to update the standard for Chilean school furniture considering the students' anthropometric data. The used sample involved 3,078 students. Data collection included 8 anthropometric dimensions. A strict procedure was followed to define 6 furniture school dimensions. The definition of the compatibility between students' characteristics and furniture dimensions was done using the concept of mismatch computed through a set of equations. The results shows differences in mismatch levels between the two compared approaches, with lower mismatch found with the new proposed approach, called the updated standard (UpS). There are also differences between the two compared approaches for cumulative fit, with 8% and 17% of the students fitting into the current and proposed standard, respectively. The obtained results reflect the need to update the data presented by the current Chilean standard. Relevance for industry: this paper presents relevant data to be used both for the school furniture designers, as well as for those responsible for the furniture selection at schools. Also, proves that school furniture standards need to be updated periodically to better fit the students' anthropometric characteristics.

Keywords: Classroom, students, anthropometry, seat, mismatch.

8.1. Introduction

Students take part in one of the most sedentary occupations –school attendance– where permanent habits of sitting are formed (Lueder and Berg Rice, 2008; Zacharkow, 1987). Being seated for a long period of time on school furniture is being associated with reports of musculoskeletal discomfort and pain (Fallon and Jameson, 1996). School furniture is a key factor for the adoption of proper posture and consequently, greater productivity for the individual. For example, the high level of mismatch between students and school furniture is being associated with adolescent low back pain (Milanese and Grimmer, 2004). Other authors, such as Linton et al. (1994), verified that the use of a chair with a curved seat and a desk with an inclination produced a reduction in

musculoskeletal symptoms in comparison to the use of a desk with a flat top (parallel to the floor) and a detached chair with a straight back and seat placed at a 90° angle.

While it is acknowledged that there is a multifactorial nature of causality of adolescent spinal symptoms, it is contended that the degree of mismatch between child anthropometry and school furniture set-up should be further examined as being a strong and plausible factor in the occurrence of adolescent lower back pain (Milanese and Grimmer, 2004).

To avoid the mismatch problem, one the best possible solutions is adjustability. Yeats (1997) argues that it is difficult to encourage proper posture early in life without the support of adjustable chairs, desks and tables in the classroom. However, scalability became a more real and cheaper solution and is reflected in the increase in the number of published standards regarding school furniture in different countries, such Chile (INN, 2002), Colombia (ICONTEC, 1999), the European Union (CEN, 2012), Japan (JIS, 2011) and the United Kingdom (BSI, 2006).

Recently a study published, concluded that the Chilean student population has increased in stature over the past two decades (Castellucci et al., 2014b). The authors also pointed out that this positive secular trend was observed in other anthropometric measures, such as Popliteal Height (PH), Hip Width (HW) and Buttock-Popliteal Length (BPL). Accordingly, they concluded that using Chilean Standard 2566 (ChS) data for furniture size selection will result in a high level of mismatch regarding Desk Height (DH) and Seat Depth (SD).

Due to the mentioned evolution of the students' anthropometric characteristics, it is of paramount importance that the considered values for student anthropometrics in furniture standards are able to be monitored and updated to reflect the observed changes in the student population, namely to reflect the so-called secular growth observed in several populations. Considering this, the aim of the current paper is to generate data for updating the existing standard for Chilean school furniture taking into account the students' anthropometric data.

8.2. Methods and Procedure

8.2.1. Defining the sample

The sample was defined using the principles defined in ISO 15535 (2012). In Chilean students, growth seems to be influenced by socio-economic status. It has previously been observed that children of higher socio-economic status are, on average, taller than those of lower and medium socio-economic status (Castellucci et al., 2010; Muzzo, 2003). Furthermore, in Chile there is a strong relation between family income and school administration type, i.e. children of lower, medium and high socio-economic status are more likely to attend to public, semi-

public and private schools, respectively (González et al., 2004). Due to this, the selection strategy considered a stratified random sample design regarding the three types of elementary school administrations in Chile: (1) public school, where parents do not have to pay for their children's studies; (2) semi-public, where both the parents and the government pay for the education; and (3) private school, where all involved costs must be assumed by parents.

The estimated student population of basic and secondary schools in the Valparaíso Region during 2010 was 243,490 students, where 26.2%, 64.6% and 9.2% of the students went to public, semi-public and private schools, respectively. Considering a 50% prevalence of school furniture mismatch ($p=0.5$ to obtain the largest sample), with 3% accuracy, 95% confidence intervals and 15% loss, the theoretical sample size is 1,251 students. However, based on the Chilean education system, every school has 12 grades, with students ranging from the age of 5 to 19 years old, and in order to cover all of them, it was decided to use a random sample of at least 20 students per grade, keeping the proportionality of each cluster. The final sample involved a group of 3,078 students (1,397 females and 1,681 males).

8.2.2. Before data collection

The measurements process was carried out by two survey teams composed of four people in each team: a measurer, a recorder, an organizer and another person to support the measurer. To avoid fatigue and monotony, the team members were able to switch from measurer to organizer and from recorder to measurer support.

Before starting the survey, the measurement teams underwent a 2-week training session, including a theoretical approach about anthropometrics as well as practical instructions. They spent considerable time practicing the measurements to achieve high consistency between measurers. At the end of the training session, both inter- and intra-measurer reliability were assessed by using the Intraclass Correlation Coefficient (ICC) model's "two-way mixed" and "absolute agreement" types. Correlations were interpreted according to the ranges suggested by Portney and Watkins (2008): $ICC \geq 0.50$ was interpreted as moderate and $ICC \geq 0.75$ was interpreted as strong. The results from Table 8.1. shows that measurers have a strong value of inter- and intra-reliability.

Table 8.1. Intra- and inter-measurer reliability (ICC values)

Measurers	PH	SUH	EHS	BPL	TT	HW	SHS	S
Measurer 1	0.905	0.886	0.874	0.968	0.825	0.878	0.945	0.959
Measurer 2	0.961	0.874	0.902	0.898	0.846	0.915	0.932	0.989
Measurer 3	0.925	0.902	0.861	0.945	0.814	0.898	0.912	0.999
Measurer 4	0.916	0.884	0.842	0.936	0.882	0.912	0.956	0.984
Inter-measurers	0.904	0.845	0.842	0.882	0.812	0.841	0.925	0.974

Popliteal Height (PH), Subscapular Height (SUH), Elbow Height Sitting (EHS), Buttock Popliteal Length (BPL), Thigh Thickness (TT), Hip Width (HW), Shoulder Height Sitting (SHS), Stature (S).

8.2.3. Data collection

The data collection started after its approval by the Committee of Ethics at the School of Medicine from the Universidad de Valparaíso. Permission to conduct this research was obtained from the headmaster of each of the considered schools. Additionally, written consent was obtained from parents and students before starting the measurement procedures.

The data collection was carried out during the 2012 Chilean academic year (March to December), the range of days spent in each school ranged from 1 to 4 days, depending on the number of students at each location.

A standard procedure was followed to collect the anthropometric measurements. The procedure indicates that the anthropometric measures need to be performed from the right side of the subjects while they are sitting in an erect position on a height-adjustable chair with a horizontal surface, with their legs flex at a 90° angle, and with their feet flat on an adjustable footrest. During the measurement process, the subjects were without shoes and were wearing shorts and t-shirts. The following anthropometric measures (Table 8.2.) from ISO 7250 (1996) need to be considered in order to estimate the most important furniture dimensions.

Table 8.2. Anthropometric measurements considered in the study

Anthropometric measurements	Definition
Shoulder height sitting (SHS)	Vertical distance from subject's seated surface to the acromion.
Elbow height sitting (EHS)	Taken with a 90° angle elbow flexion, as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
Thigh thickness (TT)	The vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
Buttock popliteal length (BPL)	Taken with a 90° angle knee flexion as the horizontal distance from the posterior surface of the buttock to the popliteal surface.
Popliteal height (PH)	Measured with 90° knee flexion, as the vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface).
Subscapular height (SUH)	The vertical distance from the lowest point (inferior angle) of the scapula to the subject's seated surface.
Hip width (HW)	The horizontal distance measured in the widest point of the hip in the sitting position.
Stature (S)	Determined as the vertical distance between the floor and the top of the head and measured with the subject erect and looking straight ahead (Frankfort plane).

8.2.4. Defining the levels of the new school furniture standard

To determine the dimensions and characteristics of different sizes of school furniture, Seat Height (SH) should be the starting point and the design needs to be based on a bottom-top approach considering the following principles.

SH: Most of the researchers have concluded that PH should be higher than SH (Mokdad and Al-Ansari, 2009; Molenbroek and Ramaekers, 1996; Parcels et al.,1999); otherwise, most students will be unable to rest their feet on the floor properly, thus causing compression of vascular and neural structures going along the popliteal

space (Milanese and Grimmer, 2004) and a less stable position for writing. However, if SH is significantly lower than PH, at more than 4 cm (UNESCO, 2001), this will increase the compression in the buttock region (García-Molina et al., 1992). Equation 1 shows that SH has to be higher than $\cos 30^\circ$ of PH plus the shoe correction (SC) to avoid an extension of more than 30° relative to the vertical. This is relevant since with more extension the feet will not be placed flat on the floor and the thighs would not be sufficiently supported, causing discomfort. On the other hand, SH has to be lower than $\cos 5^\circ$ of PH plus SC to ensure that the student will sit in a chair high enough so that both feet are placed entirely on the floor, while also avoiding compression in the buttock region (García-Molina et al., 1992).

$$(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ \quad (\text{Eq. 1})$$

After applying Equation 1, a low and high limit will be defined. The method of splitting the sample regarding PH is recommended by a several authors (Evans et al., 1988; Gutiérrez and Apud, 1995; UNESCO, 2001). For example:

- One possibility is to take the highest limit of the lower PH value and that will be our first size of school furniture.
- Then, 4 cm can be added to the previous value to generate the second size and then 4 cm more need to be added to the subsequent levels.
- Once all of the levels are determined, the sample will be split regarding their PH limits.
- Some students will be able to fit into SH in two different school furniture sizes due to the low and high limit from Eq. 1.

Once the samples have been split into the different SH sizes, the following recommendation needs to be considered for each group in order to define the most important furniture dimensions (Figure 8.1.)

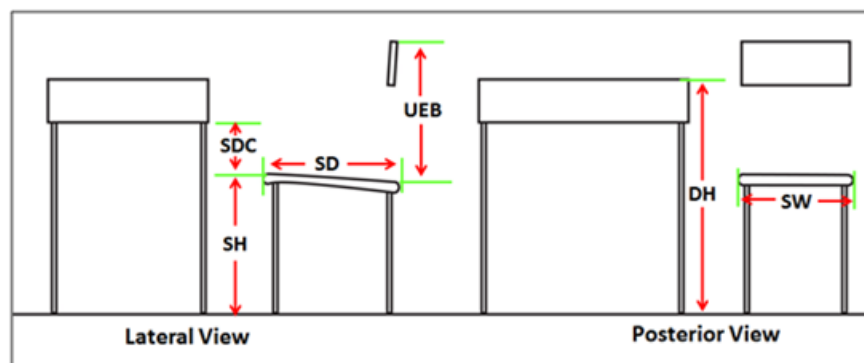


Figure 8.1. Furniture dimensions considered in the study

SD: BPL is the anthropometric measure used to designate the size of the SD (Helander, 1997; Khalil et al., 1993; Orborne, 1996). If the SD is greater than the BPL, the student will not be able to use the backrest of the seat to support the lumbar spine without compression of the popliteal surface (Milanese and Grimmer, 2004). To avoid this, it is likely that the student will generally move their buttocks forward toward the edge of the seat, as suggested by Panagiotopoulou et al. (2004). This improper usage of the backrest causes kyphotic posture (Khalil et al., 1993; Pheasant, 1991). On the other hand, if the SD is considerably shorter than the BPL of the student, then the thigh will not be fully supported and extra pressure will be distributed on the back of the thigh, causing discomfort (Pheasant, 2003). The applied equation is:

$$SD = 0.95BPL \text{ from the P5 of each group} \quad (\text{Eq. 2})$$

SW: To avoid discomfort and mobility restrictions, the SW should be higher than HW (Evans et al., 1988; Helander, 1997; Orborne, 1996; Oyewole et al., 2010). In this case, the corresponding equation is:

$$SW > HW \text{ from the P99 of each group} \quad (\text{Eq. 3})$$

UEB: When students use a chair with UEB higher than SUH, this will result in compression of the scapula and a reduction in arm and trunk mobility (García-Acosta and Lange-Morales, 2007; Orborne, 1996). As a result, the equation is:

$$UEB < SUH \text{ from the P1 of each group} \quad (\text{Eq. 4})$$

SDC: SDC is considered appropriate when it is higher than thigh thickness (TT) (Molenbroek et al., 2003). Also, Mandal cited by Garcia-Acosta and Lange-Morales (2007) proposes that the SDC should be 2 cm higher than TT. The equation for this furniture dimension is:

$$SDC > 2 + TT \text{ from the P99 of each group} \quad (\text{Eq. 5})$$

In the literature it is possible to observe different equations or criteria regarding DH:

- a) EHS is the major criterion for DH (García-Acosta and Lange-Morales, 2007; Milanese and Grimmer, 2004; Molenbroek et al., 2003; Sanders and McCormick, 1993). It is also accepted that EHS + SH can be considered as the minimum height of DH in order to provide a significant reduction on spinal loading (Occhipinti et al., 1985).

- b) If the P5 of EHS is applied, the students with higher values of EHS are forced to bend their torso forward, with their body weight supported by the arms. This will result in a kyphotic spinal posture with round shoulders (Zacharkow, 1988).
- c) Molenbroek et al (2003), proposed the P95 of the EHS + SH. This could cause some problems since the students with the lowest values of EHS will be forced to flex and abduct their upper arms as well as raise their shoulders. Thus, in the opinion of García-Molina et al. (1992), may result in more muscle workload, discomfort and pain in the shoulder region. If this is the case for only one upper limb, it will result in an asymmetrical spinal posture (Zacharkow, 1988).
- d) To avoid the aforementioned problem, Parcels et al. (1999) considered that acceptable DH depends not only on EHS, but also on the shoulder flexion and abduction angles. The minimum DH is defined by EHS. In the case of the maximum DH, Chaffin and Anderson's principles (1991) were considered with shoulder flexion and shoulder abduction angles of 25° and 20°, respectively (Equation 11, Table 8.3.).

Despite all these arguments, it is not possible to define a convincing equation or special criteria for DH. Also, Castellucci, Arezes, and Molenbroek (2014a) shows that the interrelation between the criteria for DH (Equation 11, Table 8.3.) and SDC can be contradictory, even in ideal conditions. From the data of 2,261 students, the results show that 37% of the students will use a high DH if Chaffin and Anderson's principles are considered (Chaffin and Anderson, 1991). This situation also can be explained by the different values of TT and EHS.

However, as previously mentioned, the design of school furniture begins with SH. Secondly, the students need some space under the table that should be large enough to push the chair under the table and still have enough space to allow for the movement of their legs (Eq. 5). A possible equation could be:

$$DH = (2 + TT \text{ from the P99 of each group}) + (\text{table thickness}) \quad (\text{Eq. 6})$$

8.2.5. Defining the levels of mismatch

In the literature, there is considerable variability in the equations that can be used to test the mismatch between anthropometric measures and furniture dimensions (Castellucci et al., 2014a). In this study, 6 furniture dimensions were evaluated, applying the methodology proposed by Castellucci et al. (2014a) (Table 8.3.). Some of the equations are two-way, i.e. both the minimum and maximum limits were considered. In these cases, three categories were defined: (1) "Match" level, when the furniture dimensions are between the minimum and maximum limits; (2) "High mismatch" level, when the maximum limit of the equation is lower than the furniture dimension, indicating that the furniture dimension is higher than needed; and, (3) "Low mismatch" level, when

the minimum limit of the equation is higher than the furniture dimension – in this case, the furniture dimensions are lower than the recommended level.

Table 8.3. Proposed methodology for evaluating school furniture suitability

School furniture dimension	Mismatch equation	Observation
SH	Eq. 1: $(PH + SC) \cos 30^\circ \leq SH \leq (PH + SC) \cos 5^\circ$	SC: (2 cm)
SD	Eq. 7: $0.80BPL \leq SD \leq 0.95BPL$	
SW	Eq. 8: $HW < SW$	
UEB	Eq. 9: $SUH \geq UEB$	
SDC	Eq. 10: $TT + 2 < SDC$	
DH	Eq. 11: $(SH - (\sin X^\circ SD)) + EHS \leq DH \leq (SH - (\sin X^\circ SD)) + EHS * 0.8517 + SHS * 0.1483$	

Seat Height (SH), Seat Depth (SD), Seat Width (SW), Upper Edge of Backrest (UEB), Seat to Desk Clearance (SDC), Desk Height (DH), Popliteal Height (PH), Shoe Correction (SC), Buttock Popliteal Length (BPL), Hip Width (HW), Subscapular Height (SUH), Thigh Thickness (TT), Elbow Height Sitting (EHS), Shoulder Height Sitting (SHS).

8.3. Results

8.3.1. Sample

It is important to mention that the initial number of students participating in the study was 3,181, but after checking the collected data, 103 students were excluded from the sample due some of the following problems: the use of the wrong anthropometer extension dimensions, a change in the order number and an addition of an extra zero or a misplaced comma.

The final sample, gathered during 2012, came from 18 schools that were randomly selected from a list given by the Regional Ministerial Secretary of Education and involved a group of 3,078 students (1,397 females and 1,681 males), with ages ranging from 5 to 19 years old (11.7 ± 3.5).

The descriptive statistics of the eight anthropometric measures of the students from the different types of schools are presented in Table 8.4.

Table 8.4. Anthropometric measures of the considered sample

Anthropometric measures (cm)	Public (n=815)		Semi-public (n=1,946)		Private (n=317)	
	Mean	S.D	Mean	S.D	Mean	S.D
S	148.9*	16.6	147.8 [□]	16.4	151.8* [□]	16.9
SHS	51.2*	6.4	51.4 [□]	6.6	52.4* [□]	6.4
EHS	20.9	3.4	20.6	3.6	20.5	3.3
TT	13.6*	2.4	13.6 [□]	2.3	14.3* [□]	2.0
BPL	42.2*	5.1	42.5 [□]	5.1	43.5* [□]	5.2
PH	38.5 [°]	4.3	37.9 [°]	4.3	38.5 [□]	4.3
SUH	38.4*	5.0	38.1 [□]	5.1	39.7* [□]	5.0
HW	32.3	4.6	32.6	4.7	32.4	4.6

* p < 0.05; [□] p < 0.05; [°] p < 0.05;

8.3.2. Defining the school furniture dimensions

As previously mentioned, the procedure to update the dimensions of the standard started with SH and the design needs to be based on a bottom-top approach.

The minimum value gathered of PH from the entire sample was 26 cm. However, considering the result of the highest limit from Equation 1 using SC of 2 cm, the first SH size was 28 cm (Table 8.5.). This is true despite the fact that some authors (Gutierrez and Apud, 1995; UNESCO, 2001) suggest that 4 cm can be added to the previous value to generate the second size and then 4 cm more must to be added to the subsequent levels. The current study will take this advice with some caution since this can be true for the second and third levels (Table 8.5.). However, 5 cm can be added for the fourth and fifth levels since with the highest value of SH's biggest range of PH can be fit. As an example, the 28 cm of SH defined in the first level will fit a range of 26 cm to 30 cm of PH, the 32 cm of SH defined in the second level will fit a range of 30.1 cm to 34.6 cm of PH, the 36 cm of SH defined in the third level will fit a range of 34.1 cm to 39.3 cm of PH, the 41 cm of SH defined in the fourth level will fit a range of 39.2 cm to 45 cm of PH and the 46 cm of SH defined in the fifth level will fit a range of 44.2 cm to 50.8 cm of PH. The fifth level will fit the 50.4 cm from the highest value of PH measured in this sample.

As expected, after splitting the entire sample according to their PH limit, some students were able to fit into SH in two different school furniture sizes or levels due to the low and high limit from Equation 1. Those students were assigned to the higher furniture level since most of the students preferred a higher chair (Mandal, 1982).

Finally the Equations 2 to 6 were applied to define the remaining school furniture dimensions of the UpS (Table 8.5.). Regarding Equation 6, the value considering table thickness was 7 cm since it was the minimum value considered for the structure in the ChS.

Table 8.5. School furniture dimensions (cm) from Chilean Standard 2566 (ChS) and the Updated Standard (UpS)

School Furniture Dimension (cm)	School Furniture levels									
	1		2		3		4		5	
	ChS	UpS	ChS	UpS	ChS	UpS	ChS	UpS	ChS	UpS
SH	30	28	34	32	38	36	41	41	45	46
SD	27	28	29	31	33	35	39	40	39	43
SW	34	32	34	36	38	42	40	44	40	44
UEB	27	27	29	28	32	31	37	34	37	37
SDC	14	17	16	18	18	20	20	22	21	22
DH	51	52	57	57	63	63	68	70	73	70

8.3.3. Allocation of school furniture from the UpS

Despite the fact that the standards published worldwide for furniture selection tend to use, as a reference, Stature (S) for this new standard, the authors suggest the use of PH due to the following.

- Student growth differs with age. For example, before puberty, the legs grow more rapidly than the trunk and in adolescents, the growth spurt is largely in the trunk (Bass et al., 1999).
- Molenbroek et al. (2003) demonstrated, by using ellipses, that the SH proposed in standard PrEN 1729 is too high for most of the children with S of 1,200 mm.
- Hibarú and Watanabe (1994) found that the chair size selection was strongly correlated with the PH in 124 students from the fourth grade.
- Finally, the results from Castellucci et al. (2015) show that when using PH for classroom furniture selection, higher levels of match were obtained for the two more important furniture dimensions. Additionally, it also presents a better cumulative fit than Stature.

Table 8.6. presents the distribution of the different levels of school furniture using PH as reference.

Table 8.6. Percentages of students by grade using the different levels of the UpS

School Furniture levels	School Grade											
	1	2	3	4	5	6	7	8	9	10	11	12
1	57	12	1	1								
2	43	72	43	14	5	1						
3		16	54	80	74	47	37	18	15	19	14	11
4			2	5	21	51	60	73	67	66	69	72
5						1	3	9	18	15	17	17

8.3.4. Comparing the level of mismatch of the UpS versus the ChS

Despite the fact that the ChS uses the Stature for allocation or selection of the school furniture, the procedure for assigning the level of school furniture and analysing the level of mismatch between the two standards was done using PH. For example, if the student presents 40 cm of PH and considering an addition of 2 cm of SC, the total value will be 42 cm and the students will be assigned to the fourth level of the ChS and the UpS. After having done this procedure for each of the participants in the sample, the mismatch equations from Table 8.3. were applied.

The analysis of the mismatch level of the ChS and the UpS starts with the two-way equation (Figure 8.3.), specifically for SH. For this dimension, the difference between both standards is very small since the UpS presents a 100% match and the ChS presents a 99% match. The remaining 1% corresponds to a high mismatch where the students will not find proper school furniture dimensions of the ChS since all of them present lower PH (with SC) compared to the minimum considered by the ChS (30 cm, see Table 8.5.).

The lowest level of SD from the ChS compared with those from the UpS are responsible for the large number of students that will find the seat too shallow (Figure 8.2.), for which their thighs would not be sufficiently supported and would generate discomfort (Pheasant, 2003).

Finally, Figure 8.2. shows that DH presents the highest level of mismatch. Furthermore, 22% and 17% of match are presented for the UpS and the ChS, respectively.

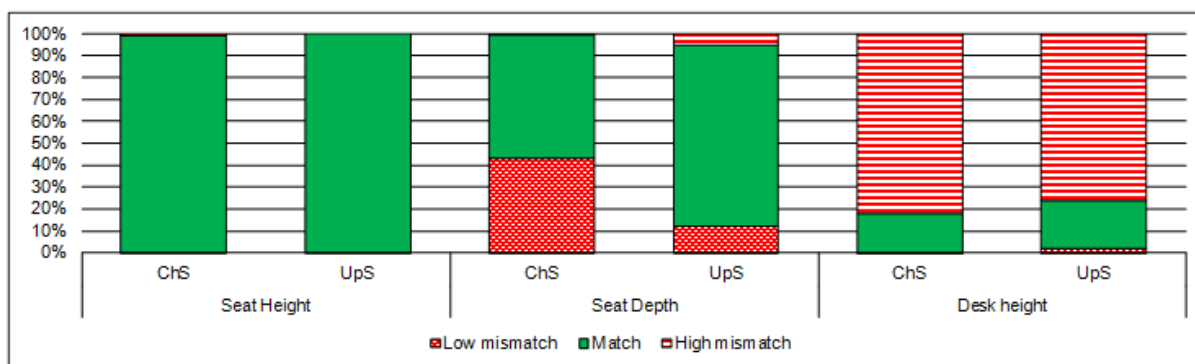


Figure 8.2. Mismatch percentages for two-way equation considering the school furniture standards

Regarding the one-way equations, the level of match is higher for both standards in 3 different dimensions (Figure 8.3.). Furthermore the differences between standards are 8%, 3% and 10% for SW, UEB and SDC, respectively.

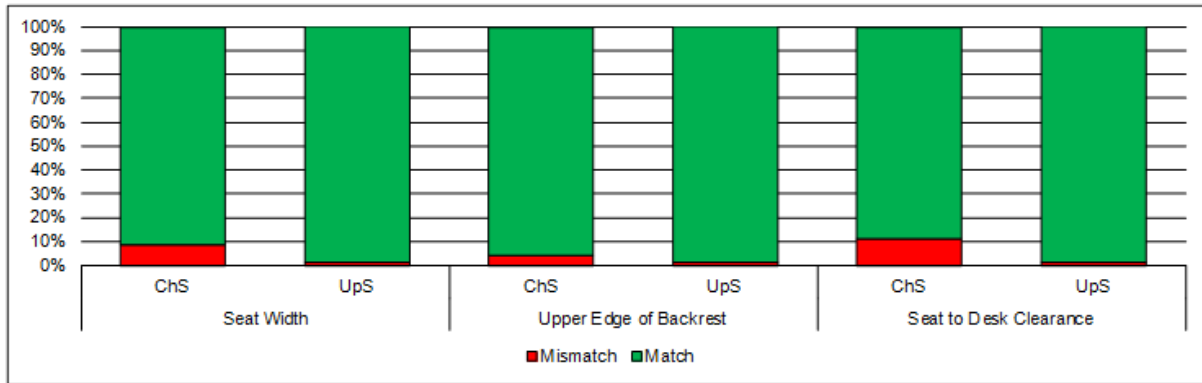


Figure 8.3. Mismatch percentages for one-way equation considering the school furniture standards

In order to improve the analysis, Figure 8.4. shows the percentage of estimated “cumulative fit” by using the two standards. The cumulative fit is defined as the match that takes into account the cumulative values of the different furniture dimensions under analysis (Castellucci et al., 2014a). The obtained results show that the higher level of cumulative fit (or match) can be reached by using the UpS.

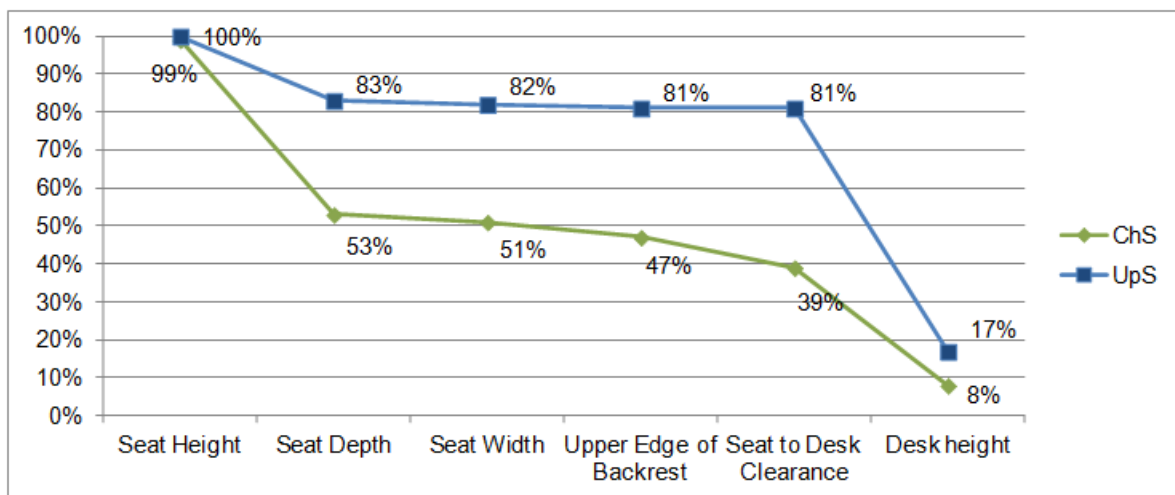


Figure 8.4. Cumulative fit for the analysed school furniture standards

8.3.5. Data Availability

The collected data are online available for designers and researcher on www.dined.nl

8.4. Discussion

Despite the fact that the aim of this study was to generate data to support an update of the standard for Chilean school furniture considering the students' anthropometric data, the authors tried to describe the whole process of considering applied anthropometrics when designing furniture for school classrooms.

It is essential to consider some aspects before the data collection. Among these is the need to define clear procedures to consider before data collection is of paramount importance. These procedures include the approval of the study by the corresponding ethics commissions, the definition of the sampling strategy and the training that should be provided to the team involved in data collection. All of these aspects were considered and presented in this study. Despite that, some errors were made during the data collection process, thus leading to the exclusion of 103 subjects. This situation reinforces the need to make a preliminary data analysis and eventually filter out some common errors that are frequently observed in anthropometric data collection.

An effective sizing system should satisfy three main criteria, i.e. fewer sizes, higher coverage of the population and better fit (Chung et al., 2007). Since these three criteria may have some conflict between them, it is almost impossible to have a perfect sizing system (McCulloch et al., 1998). Regarding the first and second criteria, the present study proposed 5 levels of school furniture – the same that were proposed by the ChS (INN, 2002) to fit a population of students ranging in the ages of 6 to 18 years old. Similar results were presented by the CEN (2012) and BSI (2006), which proposed 5 levels to cover the same age range. However, the standard from Colombia (ICONTEC, 1999) is better (or apparently more efficient) in this criteria since it proposes only 4 levels and covers a broader age range (3 to 19 years old).

Regarding school furniture dimensions and fit, there are some differences between the UpS and the ChS that need to be addressed.

- At a first glance, it seems that SH levels are almost the same; however, the covered range is different since the ChS goes from 30 cm to 45 cm and the UpS goes from 28 cm to 46 cm. This difference is not reflected in the fit situation since the standards have almost the same match percentage – 99% and 100% match for the ChS and the UpS, respectively. However, it is important to mention that the level of match could drop to 82% in the ChS if the furniture selection were done, as suggested in the standard itself, by using the S.
- The dimension SD presents the highest difference, with the highest values from the UpS going from 2 cm to 4 cm in each of the 5 levels. This situation can be explained since the current sample presents the highest values of BPL compared to the sample used to develop the ChS (Castellucci et al., 2014b). Furthermore, the results of low mismatch presented by the ChS (45%) and the UpS (12%) support the idea mentioned above. Despite the fact that the UpS presents a higher level of match (Figure 8.2.), the

83% match is still lower because 90% is the minimum percentage that is considered to represent a good size design for a specific population (Nadadur and Parkinson, 2013). These results can be explained by the fact that this is more a postural problem, which is more complex than the problems of clearance and reach, since we may have limited users in both tails of the distribution (Pheasant, 2003). For example, if we apply the equation of SD from Table 8.3. to a student with 40 cm of BPL, the limit for SD will be 32 cm and 38 cm.

- Regarding the cumulative fit, it is possible to observe large differences between the UpS and the ChS (Figure 8.4.). The final results show that only 8% and 17% of students will fit in the ChS and the UpS, respectively. However, these results should be interpreted with caution since, as previously mentioned, there is a potential problem in the criteria formulation of the DH Equation (Table 8.3.), which might impair the final results.

With respect to the allocation or selection of school furniture, the UpS proposes the use of PH, not only because the majority of the most recent bibliography supports this strategy (see point 8.3.3.), but also because PH was used to define the different levels of school furniture. Additionally, it is somehow unclear why PH is not used for furniture selection in the standards published worldwide since it is clearly easier to measure this dimension compared to S (Molenbroek et al., 2003). The allocation shows that almost all grades need two levels of school furniture to fit 90% of the students. This situation can be problematic since the furniture acquisition and allocation by schools is made without considering any ergonomic criteria and, most importantly, teachers and school authorities are not aware of this. Furthermore, there is a big gap between research recommendations and their implementations (Kendrick et al., 2012). A possible solution to counteract this situation is the involvement of the government authorities, the input of the entire school community in the use of the school furniture standard and of the implications of the identified mismatch in the students' current and future health.

Finally, some limitations of this study can also be highlighted. For example, despite the fact that this study included a very large sample of participants and an extensive database, it should be acknowledged that the conclusions are somewhat limited by the fact that these are based on the analysis of a specific region of Chile.

8.5. Conclusion

Considering the data presented in this paper, some final remarks can be summarized as follows.

The dimensions of SD, SW and SDC from the UpS present important differences compared to the ChS. In what regards the SH dimension, the differences are not so relevant. However, the UpS covers a large range for the PH dimension.

Regarding the fit level, the UpS presents higher values in the 6 evaluated dimensions when compared with the ChS. Furthermore, large differences were presented for cumulative fit.

Finally, the results reflect the need to update the data presented in the ChS and the dimension used for allocation or selection of school furniture. These changes in the standard data will better reflect the current anthropometric characteristics of the students as well as minimize the observed mismatch and consequently reduce potential postural problems.

References

- Bass, S., Delmas, P. D., Pearce, G., Hendrich, E., Tabensky, A., Seeman, E. 1999. The differing tempo of growth in bone size, mass and density in girls is region-specific. *Journal of Clinic Investigation*, 104, 795–804.
- BSI (British Standard Institution). 2006. BS EN 1729-1: 2006 Furniture – Chairs and tables for educational institutions – Part 1: Functional dimensions. UK: Author.
- Castellucci, H. I., Arezes, P. M., Viviani, C. A. 2010. Mismatch between classroom furniture and anthropometric measures in Chilean schools. *Applied Ergonomics*, 41, 563–568
- Castellucci, H. I., Arezes, P. M., Molenbroek, J. F. M. 2014a. Applying different equations to evaluate the level of mismatch between students and school furniture. *Applied Ergonomics*, 45, 1123–32.
- Castellucci, H. I., Arezes, P. M., Molenbroek, J. F. M., Viviani, C. 2014b. The effect of secular trends in the classroom furniture mismatch: support for continuous update of school furniture standards. *Ergonomics* (November), 37–41.
- Castellucci, H. I., Arezes, P. M., Molenbroek, J. F. M. 2015. Analysis of the most relevant anthropometric dimensions for school furniture selection based on a study with students from one Chilean region. *Applied Ergonomics*, 46, 201–211.
- CEN (European committee for standardization). 2012. PREN 1729-1: Furniture - Chairs And Tables for Educational Institutions - Part 1: Functional Dimensions. Brussels, Belgium: Author
- Chaffin, D., Anderson, G. 1991. *Occupational Biomechanics* (2nd ed.). New York: John Wiley.

- Chung, M.-J., Lin, H.-F., Wang, M. J. 2007. The development of sizing systems for Taiwanese elementary- and high-school students. *International Journal of Industrial Ergonomics*, 37, 707–716.
- Evans, W. A., Courtney, A. J., Fok, K. F. 1988. The design of school furniture for Hong Kong school children: an anthropometric case study. *Applied Ergonomics*, 19, 122–134.
- Fallon, E., Jameson, C. 1996. An ergonomic assessment of the appropriateness of primary school furniture in Ireland. In A.F. Ozok and G.Salvendy (Eds.), *Advances in Applied Ergonomics*. pp. 770–773. West Lafayette, USA .
- García-Acosta, G., Lange-Morales, K. 2007. Definition of sizes for the design of school furniture for Bogotá schools based on anthropometric criteria. *Ergonomics*, 50, 1626–1642.
- García-Molina, C., Moraga Tortosa, L., R., Verde, V. 1992. *Guía de Recomendaciones para el Diseño de Mobiliario Ergonómico*. Valencia: Instituto Biomecánico de Valencia.
- González, P., Mizala, A., Romaguera, P. 2004. Vouchers, Inequalities and the Chilean Experience. Santiago de Chile: CEA.
- Gutiérrez, M., Apud, E. 1995. Ergonomía aplicada al diseño de mobiliario escolar. *Cuaderno Médico Social*, 36, 18–23.
- Helander, M. 1997. Anthropometry in workstation design. In M. Helander (Ed.), *A Guide to the Ergonomics of Manufacturing*. (pp. 17–28). London: Taylor & Francis.
- Hibaru, T., Watanabe, T., 1994. A procedure for allocating chairs to school children, in: *Hard Facts about Soft Machines: The Ergonomics of Seating*, R. Lueder and K. Noro, eds, Taylor & Francis, London.
- ICONTEC (Instituto Colombiano de Normas Técnicas y Certificación). 1999. Norma Técnica Colombiana 4641. *Muebles Escolares. Pupitre con Silla para Aulas de Clase*. Bogotá, Colombia: Author
- INN (Instituto Nacional de Normalización Chile). 2002. Norma Chilena 2566. *Mobiliario escolar - Sillas y mesas escolares - Requisitos dimensionales*. Santiago de Chile: Author.
- International Organization for Standardization. 1996. ISO 7250: Basic Human Body Measurements for Technological Design. Geneva, Switzerland: Author.
- International Organization for Standardization. 2012. ISO 15535: General requirements for establishing anthropometric databases. Geneva, Switzerland: Author.
- JIS (Japanese Industrial Standards). 2011. JIS S 1021. *School furniture – Desks and chairs for general learning space*. Tokyo, Japan: Author
- Kendrick, C., Jun, G. T., Gyi, D. 2012. Primary School Children 's Working Areas : The Gaps between research recommendations and their implementation. In M. Anderson (Ed.), *Contemporary Ergonomics and Human Factors 2012: Proceedings of the international conference on Ergonomics & Human Factors* (pp. 99–106). Blackpool, UK: Taylor & Francis.

- Khalil, T. M., Abdel-Moty, E. M., Rosomoff, R. S., Rosomoff, H. L. 1993. *Ergonomics in Back Pain: A Guide to Prevention and Rehabilitation*. New York: Van Nostrand Reinhold.
- Linton, S. J., Hellsing, a L., Halme, T., Akerstedt, K. 1994. The effects of ergonomically designed school furniture on pupils' attitudes, symptoms and behaviour. *Applied Ergonomics*, 25, 299–304.
- Lueder, R., Berg Rice, V.(2008. *Ergonomics for children*. London: Taylor & Francis.
- Mandal, A. 1982. The correct height of school furniture.Human Factors: The Journal of the Human Factors and Ergonomics Society, 24, 257–269.
- McCulloch, C. E., Paal, B., Ashdown, S. A. 1998. An optimisation approach to apparel sizing. *Journal of the Operational Research Society*, 49, 492–499.
- Milanese, S., Grimmer, K. 2004. School furniture and the user population: an anthropometric perspective. *Ergonomics*, 47, 416–426.
- Mokdad, M., Al-Ansari, M. 2009. Anthropometrics for the design of Bahraini school furniture. *International Journal of Industrial Ergonomics*, 39, 728–735.
- Molenbroek, J. F. M., Kroon-Ramaekers, Y. M. T., Snijders, C. J. 2003. Revision of the design of a standard for the dimensions of school furniture. *Ergonomics* , 46, 681–694.
- Molenbroek, J., Ramaekers, Y. 1996. Anthropometric design of a size system for school furniture. In I. S. A. Robertson (Ed.), *Proceedings of the Annual Conference of the Ergonomics Society: Contemporary Ergonomics* (pp. 130–135). London: Taylor & Francis.
- Muzzo, B. 2003. Crecimiento normal y patológico del niño y del adolescente. *Revista Chilena de Nutrición*, 30, 92–100.
- Nadadur, G., Parkinson, M. B. 2013. The role of anthropometry in designing for sustainability, 56, 422–439.
- Occhipinti, E., Colombini, O., Frigo, C., Pedotti, A., Grieco, A. 1985. Sitting posture: analysis of lumbar stresses with upper limbs supported. *Ergonomics*, 28, 1333–1346.
- Orborne, D. J. 1996. *Ergonomics at Work: Human Factors in Design and Development* (third .). John Wiley & Sons, Chichester.
- Oyewole, S. A., Haight, J. M., Freivalds, A. 2010. The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *International Journal of Industrial Ergonomics*, 40, 437–447.
- Panagiotopoulou, G., Christoulas, K., Papanickolaou, A., Mandroukas, K. 2004. Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics*, 35, 121–128.
- Parcells, C., Stommel, M., Hubbard, R. P. 1999. Mismatch of classroom furniture and student body dimensions: empirical findings and health implications. *J. Adolesc. Health*, 24, 265–273.
- Pheasant, S. 1991. *Ergonomics, Work and Health*. London: Macmillan.
- Pheasant, S. 2003. *Bodyspace* (Second.). London: Taylor & Francis.

- Portney, L. G., Watkins, M. P. 2008. Foundations of Clinical Research: Applications to Practice (third.). Pearson/Prentice Hall, Upper Saddle River.
- Sanders, M. S., McCormick ., E. J. 1993. Applied anthropometry, work-space design and seating . In Human Factors in Engineering and Design (7th ed.). Singapore: McGraw-Hill.
- UNESCO. 2001. Guía de recomendaciones para el diseño del mobiliario escolar. Chile: Ministerio de Educación and UNESCO.
- Yeats, B. 1997. Factors that may influence the postural health of schoolchildren (K-12). Work: A Journal of Prevention, Assessment & Rehabilitation, 9, 45–55.
- Zacharkow, D. 1987. Posture: Sitting, Standing, Chair Design & Exercise. Springfield: Charles C. Thomas.

CHAPTER 9| Conclusions and future perspectives

9.1. Conclusions

This thesis has analyzed the study of the students' anthropometrics data and its application in the design of school furniture and it has included 7 interrelated studies that were included in this thesis as separate chapters/papers.

As all the studies were organised as different papers, the corresponding conclusion were already presented for most of them. Therefore, this chapter is a compilation of the main conclusions obtained through the obtained data and the analyses that were carried out and presented at each chapter.

The aim of the first paper was to determine the influence of school furniture in the students' performance and physical aspects. Within the studies that assessed children's physical aspects, most of the reviewed studies found that school furniture which fit student anthropometric characteristics resulted in an improvement in posture, EMG and discomfort/pain, with the latter being the most studied dependant variable. Only three papers studied students' performance and two presented positive results. However, those findings should be considered with caution, mainly due to the small size samples considered and the participants' characteristics, which also included participants with either behavioural or neurological issues. Regarding students' performance and physical aspects, all of the reviewed studies presented positive relevant results, specifically an increase in energy expenditure and better academic performance in class and attention span.

With the aim of determining the criteria equations for defining the (mis)match, or in(compatibility) between students and furniture, two papers were developed (Chapters 3 and 4) by using a mix methodology of systematic review and practical/field study. The results that have been obtained indicate a high number of applied equations to test 6 furniture dimensions. For Seat Height (SH), the most frequently evaluated furniture dimension, there are considerable differences between the two most cited and used equations. Regarding Upper Edge of Backrest (UEB), the equations are based on principles that are not fully explained by the corresponding authors. Most of the equations regarding Underneath Desk Height (UDH) or Seat to Desk Clearance (SDC) present one systematic error, which is to assume that students are sitting on a chair with a proper SH. It should be also acknowledged that the interrelation between the equations for evaluating the level of mismatch of SDC and Desk Height (DH) are based on contradictory criteria and therefore, it will be necessary to develop new equations for these parameters and validate them. Finally, the proposed methodology for the evaluation of school furniture suitability should allow for a more reliable and accurate analysis of school furniture.

The suitability of school furniture dimensions and the students' anthropometric characteristics in the Valparaíso Region (Chapter 5) was assessed by applying the methodology proposed in the previous chapter. The results

from this study sustain the idea in which the sample was estimated, since there is a difference between student anthropometric measures (e.g., Stature) when considering the different socio-economic status of the students, particularly between the high and the other socio-economical levels. Concerning school furniture, some differences were observed regarding the number and type of desks and chairs that exist at each school. Furthermore, high levels of mismatch in almost all the furniture dimensions analysed were noted, with the higher levels of mismatch occurring for SH, DH and SDC. Finally, it is important to mention that the results from this study are most probably influenced by the fact that the furniture acquisition by schools is made without considering any ergonomic criteria.

As there is a specific standard published in Chile for school furniture design and selection, A specific analysis of this data was also performed during this thesis. Regarding this standard for the dimensions of school furniture three main conclusions were drawn. The first two were referred at Chapter 6: (1) The Chilean student population measures in this thesis indicate a positive secular trend for Stature (S), Popliteal Height (PH), Hip Width (HW), and Bottom Popliteal Length (BPL), when comparing with the sample used to developed the Chilean Standard in 2002; (2) Using the standard data and its methodology for furniture size selection, it was verified that this selection resulted in a high level of mismatch regarding DH and Seat Depth (SD). A special attention should also be drawn to the 18% of mismatch observed in SH, since this measure is the starting point and the most important variable for furniture selection. These results support the idea that students' anthropometric data must be monitored and the standards updated to reflect the secular growth, if this is identified. The last conclusion (3) was mentioned earlier at the chapter 7 and it corresponds to the comparison between two different dimensions used for furniture selection: S, which is the currently used measure used by the Chilean Standard, and PH, the proposed dimension throughout this thesis. It can be concluded that four out of six dimensions present the lowest levels of mismatch when the school furniture is selected by S. However, for the most important furniture dimensions (SH and DH), it has obtained a better fit when PH is used. Furthermore, it can be stated that PH is the most accurate, and therefore the most appropriate, anthropometric measure for classroom furniture selection since it presents a better cumulative fit (or match) than S. This conclusion can be explained by the fact that the students presents differences in the proportion of PH and Trunk Length when comparing it across the two genders and different ages.

New data to be included in the standard for furniture design for Chilean schools were generated and presented in the last paper (Chapter 8), which was based on the results of the previous papers. The proposed updated for the standard includes the use of PH for furniture selection or allocation and it presents a proposal for five levels of school size, the same number in the current Chilean Standard. Regarding the fit level, the updated standard presents higher values in the six evaluated dimensions when compared with the current Chilean Standard. Furthermore, large differences were presented for cumulative fit.

It is also important to acknowledge some limitations of this work. In the case of Chapter 2, 3 and 4, one considered limitation can be the search process itself, which may not have allowed the identification of all studies published worldwide. Additionally, the wide variety of research approaches adopted by the studies reviewed also made it difficult to summarize all the comparison data. The results from Chapter 6, 7 and 8 are based in a very large sample of participants. However, this sample came from one specific region of Chile. Finally, it is also important to note that the formulation of the DH applied equation include a contradictory criteria with SDC equation and thus needs to be evaluated in detail.

9.2. Perspectives for future work

In recent years, much attention has been given to the study of school furniture and students' anthropometrics data. The information from this thesis provided important findings for these issues. Based on the developed work and, three main areas were identified as priority areas to develop important future work, namely:

- Further research should target the impact of new school furniture in students' performance and physical aspects, specifically by using more objective measures and with a controlled and prospective design. The idea of the new school furniture is to include a desk with tilt angle, a slight concave curve in the front and an adjustable height, and a high saddle chair, but considering that both feet must be on the floor;
- It will be necessary to develop new equations for the DH, as it seems to be contradictory with SDC equation. Firstly, the design and evaluation of school furniture begins with SH. Secondly, the students need an under table space that should be large enough to push the chair under the table and have enough space to allow for the movement of their legs. Having said that, there are not many changes that can be made to the SDC equation. However, it will be important to test those changes both in the laboratory and in the field. The criteria presented by Chaffin and Anderson (1991), i.e., 25° of shoulder flexion and 20° of shoulder abduction angles, does not take the elbow or forearm support into consideration, which may be used to reduce the strain on the shoulder. One possible hypothesis could be that, students can work with forearm support safely with higher angles than those proposed by Chaffin and Anderson.
- Finally, a school ergonomic program must be developed and tested since some of the results presented in this thesis can be influenced by different aspects such as: students do not automatically sit properly in the ergonomically designed furniture, there is a big gap between research recommendations and their implementations, furniture acquisition by schools seems to be made without considering any ergonomic criteria and, most importantly, teachers and school authorities do not seem to be aware of this. The

ergonomic program must also consider the involvement of the government authorities, the input of the entire school community in the use of the school furniture standard and of the implications of the identified mismatch in the students' current and future health. It will be also important to consider some other micro- and macro-ergonomics factors.